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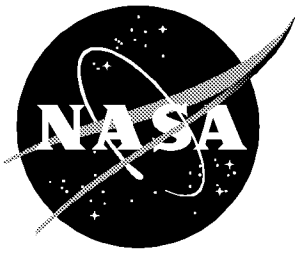

Description of the AILS Alerting Algorithm

Paul Samanant and Mike Jackson
Honeywell, Inc., Minneapolis, Minnesota

May 2000

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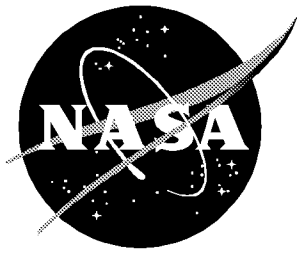

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1 Introduction and Overview

1.1 Introduction

This document is a complete description of the Airborne Information for Lateral Spacing (AILS) alerting algorithms. The documentation corresponds to the most current version of AILS used in simulation at NASA Langley Research Center (LaRC) and in test flights with NASA (B757 Aries) and Honeywell (Gulfstream IV) in CY99. The original AILS which has been documented in Reference [3], had two versions of the algorithm: - "Full AILS" and "Parameter AILS." The full version was intended for in-flight use, while the parameter version was for lab testing only. This document only describes the current version of the full AILS algorithm – the parameter AILS algorithm was not carried forward to match the full version.

Modifications to the original AILS were the result of simulation and analysis work performed at Honeywell Technology Center and at NASA Langley Research Center. The analysis at Honeywell focused on an assessment of the relative safety of the system by simulating many scenarios. This analysis uncovered some weaknesses of the original algorithm related to the circular shape of the protected region. The NASA simulation activities in the B757 Integrated Flight Deck (IFD), part of the Research Simulation Integrated Laboratory (RSIL), focused on the human factors aspects of the system design. These simulations helped tune the system parameters for pilot acceptance. Both analyses performed suggested possible modifications to the algorithms, and NASA and Honeywell engineers collaborated to agree on the changes to the algorithms.

Additional changes to the AILS algorithms were required as the focus shifted from simulation and analysis towards a real-world real-time implementation, such as dealing with non-parallel runways, offset thresholds, and non-zero runway latitude, longitude and altitude.

The equations and logic to implement the algorithm changes were designed and implemented at Honeywell Technology Center, with some assistance from Bill Capron (a Lockheed contractor at NASA LaRC).

Section 1.2 below presents a detailed list of the changes that were made to the AILS algorithm.

The latest version of AILS, which contains these changes, was coded in PASCAL and tested in simulations and flight experiments in 1999. (There is also an equivalent "C" version of the code that was used by Honeywell Technology Center to perform simulation and analysis work.)

This document provides a Software Design Document-like description of this most current AILS software.

1.2 Changes to the AILS Algorithm

Following is a list of the major changes made to the AILS algorithm.

- Added vertical dimension to alerting. This required the addition of a vertical situation determination routine. It also mandated changing from the existing point-of-closest-approach formulations in favor of the solution of a quadratic equation to obtain entry and exit times into the horizontal alert region.

- Changed from circular horizontal protection to elliptical protection zone.
- Added the capability for non-parallel runways.
- Added the capability for vertically offset runway thresholds.
- Added the capability for displaced runway thresholds.
- Added capability to handle real-world-type localizer and glide-path definitions.
- Changed from bank-angle based turn predictions to track-rate based turn predictions.
- Added actual states capability. This represents a departure from the nominal mode that requires both vertical and lateral "snapping" of the aircraft to the glide-path and localizer respectively. Much of the complication in this task involved the need to transform the elliptical alerting coefficients to an alternate coordinate system in order to slave the ellipse to the aircraft frame of reference during the actual-states mode.
- Added the protected escape zone capability (not engaged during RSIL and flight test activity).
- Removed bank angle bias.
- Revised the straight track/curved track logic in the main AILS executive Larcalert_full.
- Added logic to handle corner cases/divide by zero cases introduced by the vertical and elliptical alert region modifications.
- Added the use of a first order filter for improved track rate prediction and turn performance (and also for improved false alarm performance).
- Added maximum turn-time capability. This is a limit on the "project ahead" time when the aircraft is in a turning situation that requires AILS to perform "fan" projections. (This feature was not engaged during RSIL and flight test activity.)

1.3 Document Overview (How to Use This Document)

The following table describes the major subsections of this document.

	Section name	Description
1.0	Introduction	Introduction and list of major additions to original AILS
2.0	AILS Algorithm Overview	Provides the reader with an introduction and overview of the AILS algorithm.
3.0	AILS Coordinate Frame Descriptions	Describes the coordinate systems used in AILS. Sound knowledge and understanding of the coordinate systems used is essential for the implementation of AILS, either in simulation or in real-time systems.
4.0	AILS Top Level Description With	Describes the main functional blocks of AILS and how those blocks are organized. The flow charts further enhance understanding of the

	Section name	Description
	Flow Charts	elements and that comprise the major blocks and routines.
5.0	AILS Data Descriptions And Pseudo-code	Contains the complete descriptive data definitions as well as pseudo-code for the core AILS algorithm. The information in this section is comprehensive and sufficient for a software programmer to program the full functionality of the current core AILS algorithm.
6.0	Algorithm Pre and Post Call Requirements	Although detailed pseudo-code is provided for core AILS, some pre and post-processing is required to set up AILS and also to fully duplicate the functionality of the current implementation of AILS. This section provides descriptions on how to set up and call AILS, as well as recommended preprocessing or post processing. The information provided is absolutely required for the implementers of AILS (either for simulation or real system implementation).
7.0	AILS Equations	Some of the key equations of AILS are derived.
A	Acronyms and Abbreviations	List of acronyms and abbreviations.
B	Glossary	Descriptions of terminology.
C	References	List of references.

Table 1.3.1 Document Reference Table

2 AILS Algorithm Overview

This section provides an introduction, overview description of the AILS algorithm.

2.1 General Algorithm Description

The purpose of AILS is to provide multiple levels of alerting for pairs of aircraft that are in parallel approach situations. AILS will assess blame and issue alerts to the "blundering" aircraft prior to the issuing similar alerts to the "innocent" aircraft. The algorithm takes advantage of current aircraft states as well as known "intent" information in order to project ahead for threat determination. This forward projection is executed based on current positions, velocities, altitudes, turn rates, and climb rates. AILS threat determination consists of 2 types of alerting checks, with 2 levels for each alert type.

1. Adjacent ship threat to own ship (caution- and warning-alerts levels).
   The solid lines in Figure 2.1.1 AILS Fan and Intrusion Check Scenarios show this.
2. Own ship threat to adjacent ship (caution- and warning-alerts levels).
   The dashed lines in Figure 2.1.1 AILS Fan and Intrusion Check Scenarios show this.

Cumulatively, there are four levels of alerts that are ascending in degree of criticality. Table 2.1.1 describes these levels and their associated attributes.

alert level	alert type	associated scenario	commanded action
level 1	caution	own ship threatens adjacent ship	issue PATH alert to adjacent ship
level 2	caution	adjacent ship threatens own ship	issue TRAFFIC alert to own ship
level 3	warning	own ship threatens adjacent ship	issue EEM alert to adjacent ship
level 4	warning	adjacent ship threatens own ship	issue EEM alert to own ship

Table 2.1.1 AILS Alert Level Attributes

An aircraft that is off of its approach path and threatening another aircraft is designated in AILS nomenclature as the "intruder." The threatened aircraft is designated as the "evader." In a typical intrusion scenario where the intruders ignore their alert messages, the alerts will be issued in the following sequence:

1. Intruding aircraft pilots receive a PATH caution alert.
2. Evader aircraft pilots receive a TRAFFIC caution alert.
3. Intruder aircraft pilots receive a commanded EEM warning.
4. Evader aircraft pilots receive a commanded EEM warning.

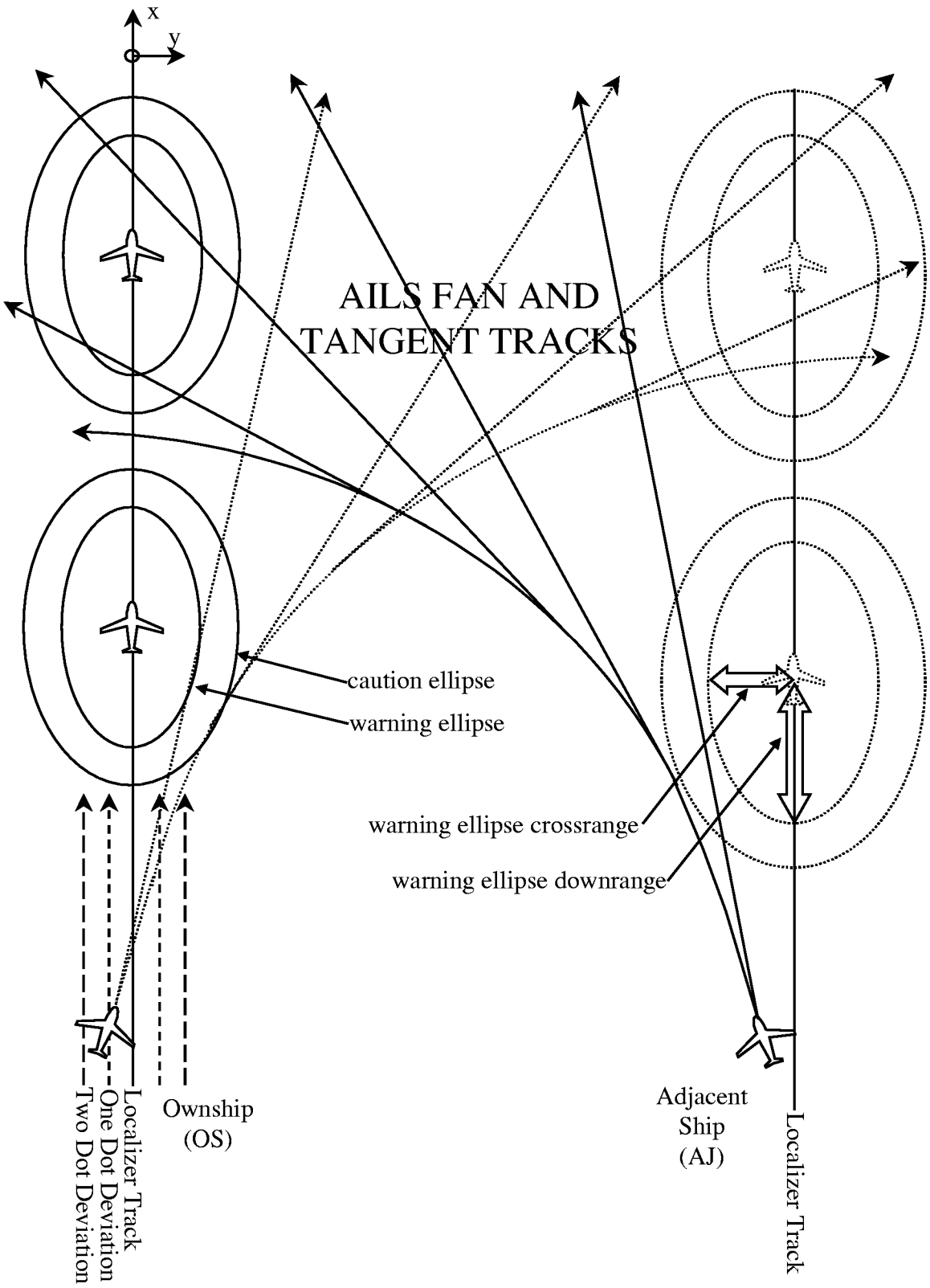

Figure 2.1.1 AILS Fan and Intrusion Check Scenarios

During AILS's threat evaluation, forward projections are performed from the current state out towards a finite time in the future. The intruder's state is projected forward to see if it will puncture the evader's protection zone. This zone consists of a linear distance above and below the aircraft, and an elliptical protection area in the horizontal plane. Table 2.1.2 shows some of the key AILS alerting parameters.

parameter	level 1	level 2	level 3	level 4
downrange (ft)	5000	3500	3400	2500
cross-range (ft)	1800	1300	1250	900
alert zone above (ft)	1800	1300	1250	900
alert zone below (ft)	1800	1300	1250	900
alert time (sec)	30	22	21	16

Table 2.1.2 Current AILS Alerting Parameters

Note that in order to achieve the desired alerting sequence as previously described and illustrated in Table 2.1.1, the alert zone sizes and alerting times decrease with the increasing alert levels.

2.2 Elliptical Protection Zone

The AILS alerting algorithm is 3-dimensional. The protected space around the aircraft is elliptical in the horizontal plane. The protected aircraft is at the center of the ellipse. Typically, the major axis of the ellipse is aligned in the direction of the final approach (See section 2.9 for the exception to this alignment). In the vertical plane, the protected region is a specified linear distance above and below the aircraft. Projections of the intruder into this protected area will cause alerts to be issued.

The protection ellipse is specified by downrange and cross-range parameters which represent the major and minor axes of the ellipse, respectively. Setting the downrange equal to the cross-range would result in a cylindrical protection zone. This cylindrical "hockey puck" was the shape of the protection zone in an initial AILS design. Analysis has shown that employing an ellipse with the major axis in the direction of travel increases performance of the overall system.

2.3 AILS Fan

AILS requires that if the intruder is executing a turn, the algorithm will project this turn through the required time. In addition to this, AILS will also assume that at designated points during the turn, the intruder may level out and fly in a straight line. These straight paths are also projected through the required time period. These straight segments are known as "tangent tracks." These projections result in a "fan" of trajectories that are evaluated for collision threat potential. The AILS "fan" represents an added level of safety check and conservatism (see Figure 2.1.1 on page 5).

2.4 AILS Forward Projection Assumptions

As AILS performs threat determinations, both aircraft states are projected forward in time. Several assumptions are made as these extrapolations are carried out:

- Both aircraft are assumed to fly with a constant ground speed.
- Unless actual states mode is in effect, the evader is assumed to be initialized on the localizer beam and to stay on the localizer beam for the duration of the current prediction times.
- The intruder is assumed to be flying a constant radius turn at the current turn rate and can level out at any time and fly straight along a track tangent to the turn arc. The current configuration is set compute turn rate based on track rate that has been derived from GPS velocities, but it can also be configured to use bank angle.
- The AILS forward search time step: (deltat AILS) is an input and is currently set to the value of 0.5 seconds. This time step will determine the search resolution when AILS is performing the intruder and evader projections in it's process of threat determination.
- The tangent tracks are computed every N time steps, where N is chosen dynamically such that the tangent tracks are taken between every 1.5 to 3.0 degrees. (The computation of the tangent track frequency assumes that the time step is 0.5 seconds, or a fraction of that. It should still work if the time step is different, but it may not produce tracks between 1.5 and 3.0 degrees

2.5 Snapping vs. Actual States

The AILS algorithm works on designated pairs of aircraft. For a particular set of aircraft, in each respective aircraft's computer, two scenarios are considered:

1. Where the own ship is considered as the intruder and the adjacent ship is considered as the evader;
2. Where the own ship is considered as the evader and the adjacent ship is considered as the intruder.

In each scenario, the intruder's current state information is used to project the intruder's anticipated position as a function of time. The evader's actual current states are used with the exception of cross-range and altitude. Instead, in accordance with the "intended states" philosophy, the evader's assumed position for cross-range and altitude are "snapped" to the localizer and glide slope, respectively. This protects the region on the intended path where the aircraft is most likely to be in the future.

If the aircraft is NOT established on its approach, its actual states will be used regardless of whether the scenario requires it to be intruder or evader. The reason for the "snapping" is the design philosophy which makes use of the known intended approach path of an aircraft.

2.6 On Approach/Off Approach Criteria For Snap Determination

If an aircraft is substantially off of it's approach, it is not appropriate to "snap" that aircraft to the approach path. "Snapping" under this condition would significantly misrepresent the position of the aircraft, which could lead to either false alarms or missed alerts. Following is the criteria used to determine if an aircraft is significantly off of its approach:

Aircraft declared NOT to be on approach if:

1. More than 2 dots of vertical deviation.
2. More than 2 dots of lateral deviation OR more than 400 ft of lateral deviation to either side of the approach path.

At very large distances from aircraft to the runway datum point, 2 dot angular offsets can result in large deviations from the center approach on the order of thousands of feet. Therefore the 400 foot lateral criteria was added to the angular dots as a limiting factor on how far AILS will snap an aircraft. The definition used for 2 dots was the following:

2 dots of horizontal deviation = 2 degrees to either side of localizer path

2 dots of vertical deviation = .7 degrees above and below the glide path

These values were hard-coded in the software. If the localizer or glide path sizes change, these values would need to be made input parameters.

The reference point for defining these angles is the Glide Path Intercept Point (GPIP).

2.7 On Approach/Off Approach Intruder and Evader Track

During AILS's threat determination scenarios, if the aircraft that is designated as the evader is determined to be on-approach, the track angle for that aircraft is considered to be congruent with the approach. This is in conformance with the AILS "snapping" philosophy. If the aircraft is determined to be off-approach, then the track angle used for the evader will be the actual track angle of the aircraft (which is specified in the runway coordinate frame). If this aircraft is in a turn, the current track of the aircraft will be used and the aircraft will be presumed to fly straight along that track.

In AILS threat determinations, the intruder's actual states are always used regardless of whether the intruder is on-approach or off-approach.

2.8 Ellipse Size Adjustments If Aircraft is Off Approach

If an aircraft is determined to be off-approach according to the criteria listed above, it is NOT snapped to the approach when it is playing the evader role during AILS threat determinations. The original AILS algorithm always snapped one aircraft to the approach path, so if that aircraft was then threatened it was obvious which aircraft was at fault and which aircraft should be alerted first. With the snapping taken away, and no other changes made, both aircraft may get an alert at a similar time. Since we have taken away a basic assumption of AILS, we need a new method of assessing blame and alerting the blundering aircraft first.

To address blame when one aircraft is off-approach, we will use the fact that they are off-approach to determine who is at fault. When one or both aircraft are off their approach the alerting parameters are modified to get the alerts to occur in the proper order. Also, the way alerts are treated is modified to properly assess blame. Table 2.8.1 below shows how the alert parameters and alert logic are modified depending upon who is off-approach.

A few general statements can be made to summarize the table below. If my aircraft is off approach, and the adjacent aircraft is on-approach, then my aircraft is blamed for all alerts. So, my aircraft's computer will use level 1 & 3 alert parameters for all 4 scenarios listed in Table

2.1.1 above, and the adjacent aircraft's computer will use level 2 & 4 alert parameters for all 4 scenarios. The blundering aircraft will thus always get the alerts first. To ensure that blame is proper assessed, the blundering aircraft will only get level 1 & 3 alerts, and the innocent aircraft will only get level 2 & 4 alerts.

	Adjacent ship is on approach	**Adjacent ship is off approach**
Own ship is on approach	Nominal ellipse parameters for own ship and adjacent ship.	Set level 1 & 3 alert parameters equal to level 2 & 4 alert parameters. If level 1 or 3 alert occurs, mark it as a level 2 or 4 alert.
Own ship is off approach	Set level 2 & 4 alert parameters equal to level 1 & 3 alert parameters. If level 2 or 4 alert occurs, mark it as a level 1 or 3 alert.	Set level 2 & 4 alert parameters equal to level 1 & 3 alert parameters.

Table 2.8.1 On Approach/Off Approach Ellipse and Alert Determinations

If both aircraft are off-path, then we no longer assess which aircraft is to blame for the collision threat. It will be likely that one aircraft is just slightly off path and the other is blundering, but they are treated equally. Both aircraft will use the level 1 & 3 alert parameters to get the alerts to occur sooner.

2.9 Protection Ellipse Frame of Reference

A protection ellipse is always centered at the protected aircraft. The orientation of the ellipse will depend on whether or not the aircraft is on or off of its approach. If an aircraft is on the approach path, the protection ellipse's orientation is slaved to that aircraft's local runway coordinate system: The major axis of the ellipse is aligned with the approach path. If an aircraft is off of the approach path, than the protection ellipses are slaved to aircraft direction of travel: The major axis of the ellipse points in the direction of that aircraft's track angle (Figure 2.9.1).

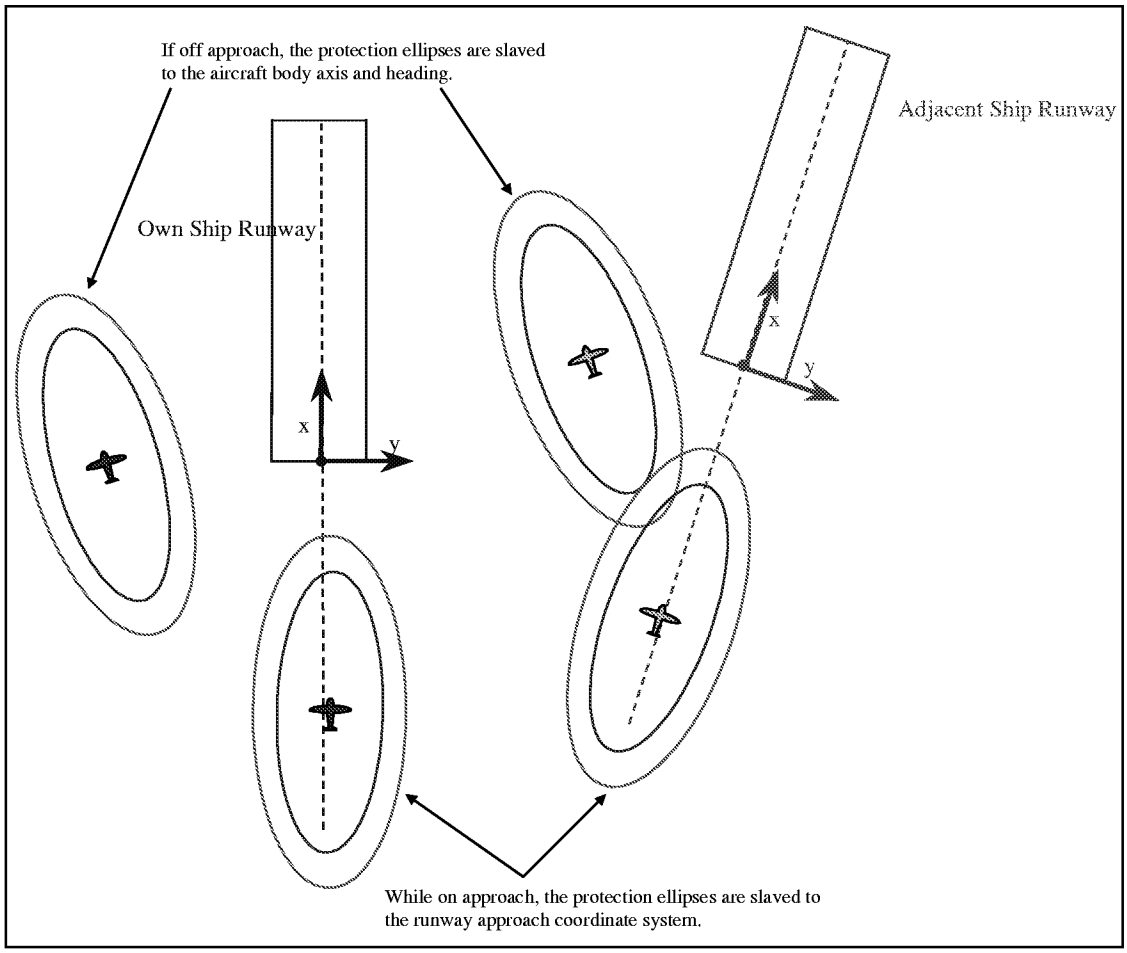

Figure 2.9.1 Ellipse Slaving To Aircraft Frame vs Approach Frame

2.10 Protected Escape Zone (Currently Disabled)

The AILS algorithm has an incorporated "protected escape zone" capability that does not use any prediction of future aircraft positions. This zone is chosen as a rectangular shape around the protected aircraft. If the other aircraft is inside of this protected area, an EEM command is issued to the protected aircraft.

The protected escape zone is defined by setting the appropriate parameters that are defined in Table 2.10.1. Lateral protection to the EEM side of the evader is extended to infinity. This protected escape zone is clearly seen in the diagram in **Figure 2.10.1**. Section 6.12.4 (on Default Protected Escape Zone Parameters) shows how to set these parameters in order to disable the protected escape zone functionality.

The original purpose of this feature was to reduce the induced-collision rate by protecting the evader escape route. However, as we tested this feature, we discovered that it not only drastically increased the frequency of false alerts, but also *increased* the frequency of induced collisions. In analyzing the nature of the induced collision scenarios, we came up with the idea

of the elliptical protection zone. The elliptical protection zone gave us the performance we were looking for, making the rectangular protected escape zone unnecessary. Therefore, the currently implemented AILS configuration has this feature disabled by selecting parameters appropriately.

Parameter	Definition
protected lateral (distance towards adjacent approach)	Lateral cross-range distance in direction of the intruder's runway. This is specified as a positive number as shown in **Figure 2.10.1**. Setting this to a large negative number pushes the zone far to the "escape" side thus effectively turning off the zone. The EEM side of the protected escape zone automatically extends to infinity.
distance ahead	Downrange distance ahead of the aircraft.
distance below	Downrange distance behind the aircraft.
distance above	Vertical distance above the aircraft.
distance behind	Vertical distance below the aircraft.

Table 2.10.1 Protected Escape Zone Parameter Definition

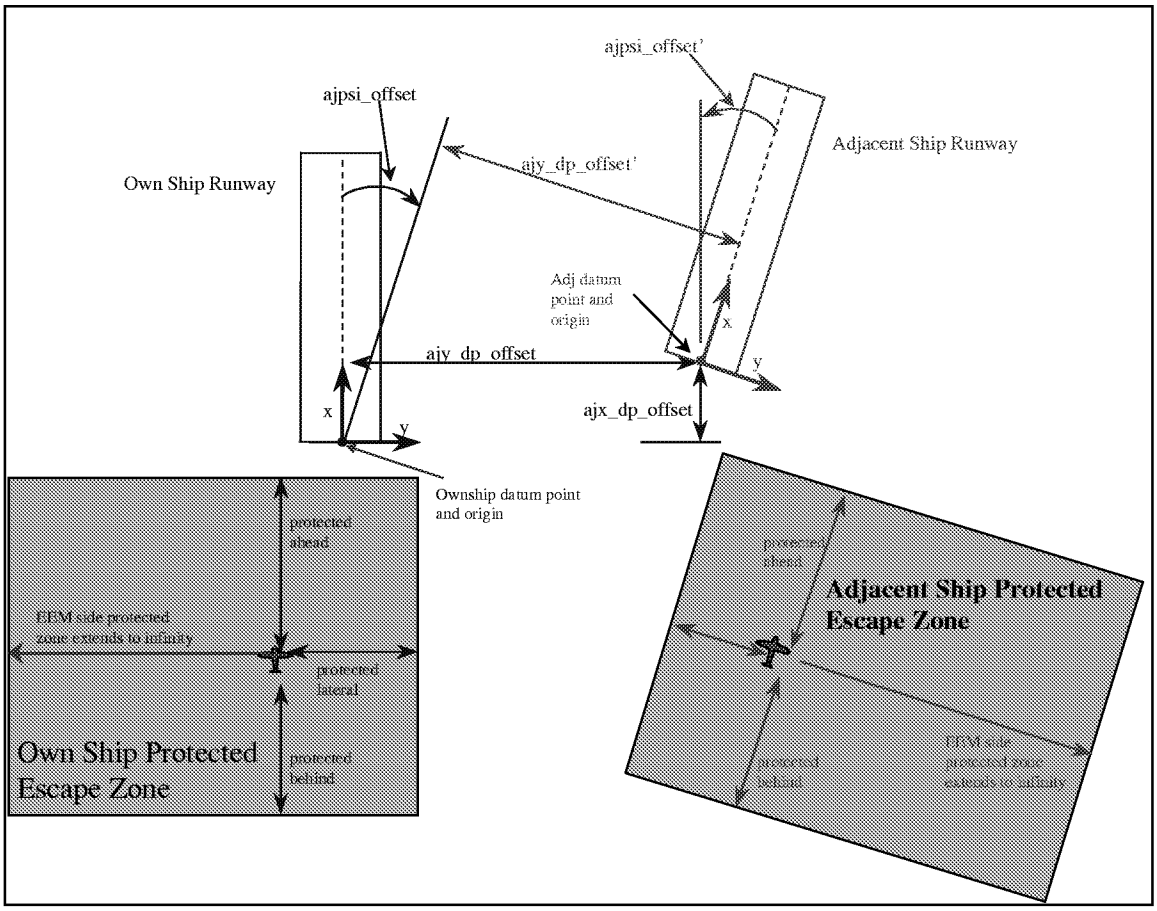

Figure 2.10.1 Protected Escape Zones

2.11 AILS Turn Time (Currently Disabled)

The AILS turn time parameter limits the length of time that AILS will project a current turn when the algorithm is performing the fan. This value is not to be confused with the normal AILS alerting time parameters which determine how far ahead AILS projects ahead. The distinguishing factor is if the aircraft is currently in a turn, the current track and the tangent tracks projections will be governed by the AILS alerting parameter, but the time that the turn is maintained will be limited by the turn time.

Example of AILS Turn Time: If the AILS turn time is set to 1 second, the current turn will be carried out for only a second. After that time, in conformance with the "fan" logic, the aircraft will be assumed to level out and fly in a straight path. The remaining time of the projection of this straight path will be governed by the appropriate caution and warning AILS alerting times.

This turn limiting was originally introduced in an effort to decrease false alarms due to turbulence and pilot over adjustments. The current default configuration is to set the turn time to a value that would render the turn time being disabled. This is done by selecting a large number that is greater than the largest AILS alerting time:

AILS turn time = 99 sec (disabled)

2.12 Track Rate Deadband

A dead band is applied to aircraft track rates that are close to zero. The purpose for this is to prevent unnecessary turns and fans resulting from minor track rate perturbations and turbulence. If an aircraft's track rate is at or below this value, a zero value is selected as the aircraft track rate. The following value of the track rate dead band reflects the value used in the most current configuration.

AILS track rate deadband = .00024 rad/sec

3 AILS Coordinate Frame Definitions

3.1 Transformation From Earth To Local Coordinates

AILS uses two coordinate systems – one aligned with the own ship's intended approach, and one aligned with the adjacent ship's intended approach. The coordinate system origins are located at the approach datum points (typically the runway thresholds), and the x-axes are aligned with the approach centerlines (typically the runway centerlines). Standard navigation data for each AILS aircraft is converted to these local coordinate systems (Figure 3.1.1).

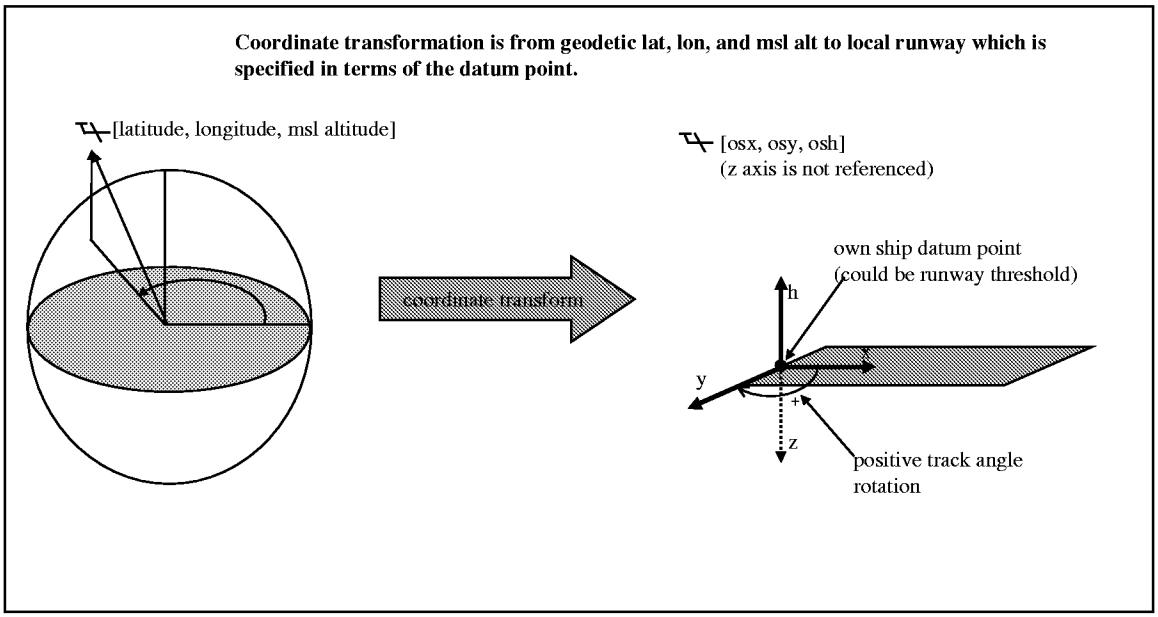

Figure 3.1.1 Transformation From Spherical Earth To Local Runway Coordinates

Note that the "z" axis points down but the altitude or "h" axis points up and is positive up. This is the main axis of vertical reference in the AILS algorithms.

3.2 Definition Of Internal AILS Coordinate System

Figure 3.2.1 defines AILS runway coordinate system as viewed from above looking down, and Table 3.2.1 describes the variables used in the Figure. Each aircraft in the AILS pair considers itself to be the **own ship**. The origin of the **own ship** coordinate system is at the center of that aircraft's datum point. The x-axis points straight down the runway length and is positive in the landing direction. The y-axis points 90 degrees to the right (from the x positive direction). The x-axis direction is commonly known as **downrange** while the y-axis direction is commonly known as the **cross-range**.

The true z axis is not referenced. Instead, altitude above the runway threshold plane (h) is used.

The **adjacent ship** refers to the aircraft performing the parallel approach with the **own ship**. The origin of the **adjacent ship** coordinate system is at the adjacent ship's datum point. The x-axis points straight down the approach centerline and is positive in the landing direction. The y-axis points 90 degrees to the right (from the x positive direction). The x-axis direction is

commonly known as downrange while the y-axis direction is commonly known as the **cross-range**.

As AILS performs it's intrusion checks it will designate one aircraft as an **intruder** and the other aircraft as the **evader**. During these checks, both aircraft have to placed in a single frame of reference. AILS chooses the **intruder frame** of reference to contain the **intruder** and **evader** positions.

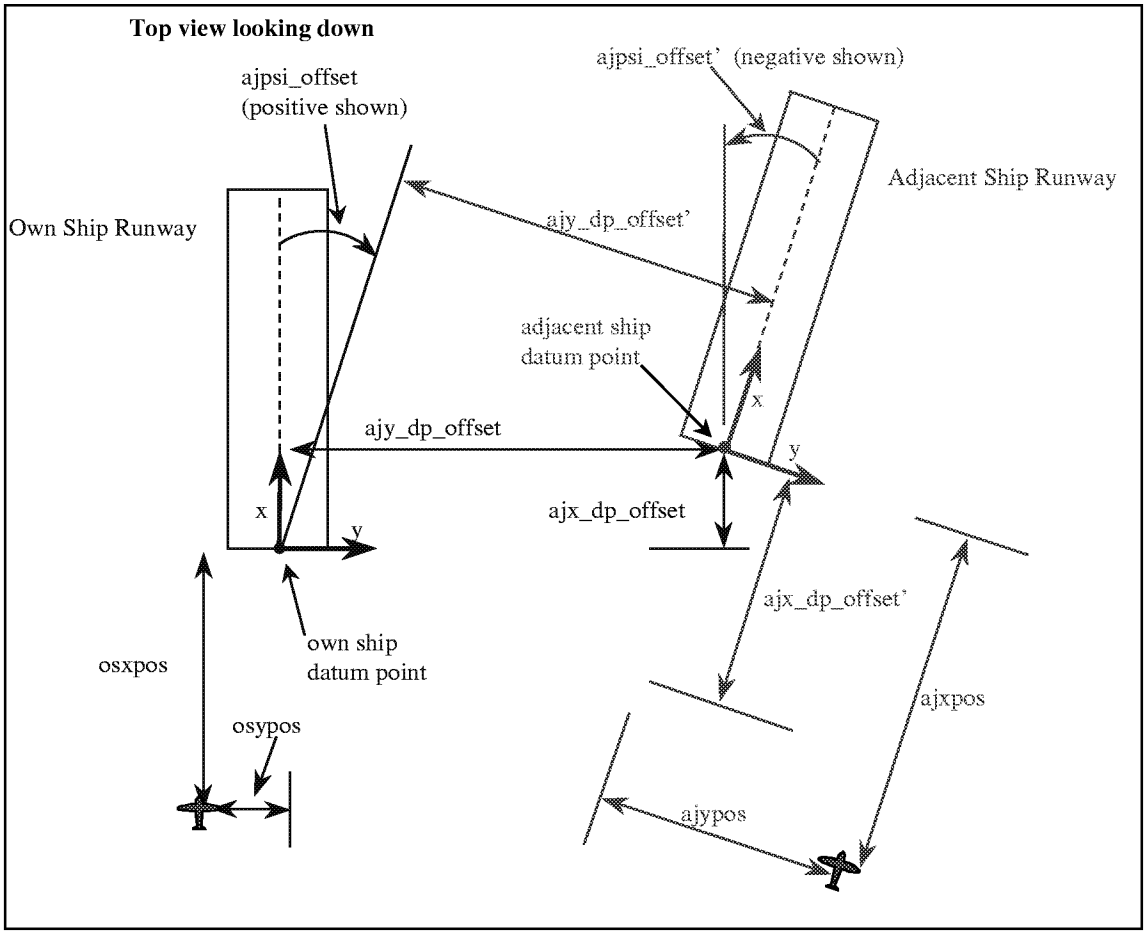

Figure 3.2.1 AILS Runway Coordinate System

variable	description
osxpos	**downrange** position of **own ship** relative to **own ship** coordinate system
osypos	**cross-range** position of **own ship** relative to **own ship** coordinate system
oshpos	h position of **own ship** relative to **own ship** coordinate system
ajxpos	**downrange** position of **adjacent ship** relative to **adjacent ship** coordinate system

variable	description
ajypos	**cross-range** position of **adjacent ship** relative to **adjacent ship** coordinate system
ajhpos	h position of **own ship** relative to **own ship** coordinate system
ajx_dp_offset	**downrange** offset of **adjacent ship** datum point from **own ship** datum point in **own ship** coordinates
ajy_dp_offset	**cross-range** offset of **adjacent ship** datum point from **own ship** datum point in **own ship** coordinates
ajh_dp_offset	**altitude** offset of **adjacent ship** datum point from **own ship** datum point in **own ship** coordinates
ajpsi_offset	angle offset of **adjacent ship** runway from **own ship** runway in **own ship** coordinate system
ajx_dp_offset'	**downrange** offset of **own ship** runway from **adjacent ship** runway in **adjacent ship** coordinate system
ajy_dp_offset'	**cross-range** offset of **own ship** runway from **adjacent ship** runway in **adjacent ship** coordinate system
ajh_dp_offset'	**altitude** offset of **own ship** runway from **adjacent ship** runway in **adjacent ship** coordinate system
ajpsi_offset'	angle offset of **own ship** runway from **adjacent ship** runway in **adjacent ship** coordinate system
x0	x position of the **intruder** aircraft relative to the **intruder frame** coordinate system
y0	y position of the **intruder** aircraft relative to the **intruder frame** coordinate system
h0	h altitude of the **intruder** aircraft relative to the **intruder frame** coordinate system
xloc	x position of the **evader** aircraft relative to the **intruder frame** coordinate system
yloc	y position of the **evader** aircraft relative to the **intruder frame** coordinate system
hloc	h altitude of the **evader** aircraft relative to the **intruder frame** coordinate system

Table 3.2.1 Definition Of AILS Runway Frame Position Variables

3.3 Side and Downrange Views of AILS Internal Coordinate System

Figure 3.3.1 shows the side view of the AILS coordinate system. The "y" axis is pointing out of the page towards the reader in this diagram. The diagram also shows the relationship between the external MSL altitude and the internal AILS variable **oshpos** which is specified relative to the runway datum point.

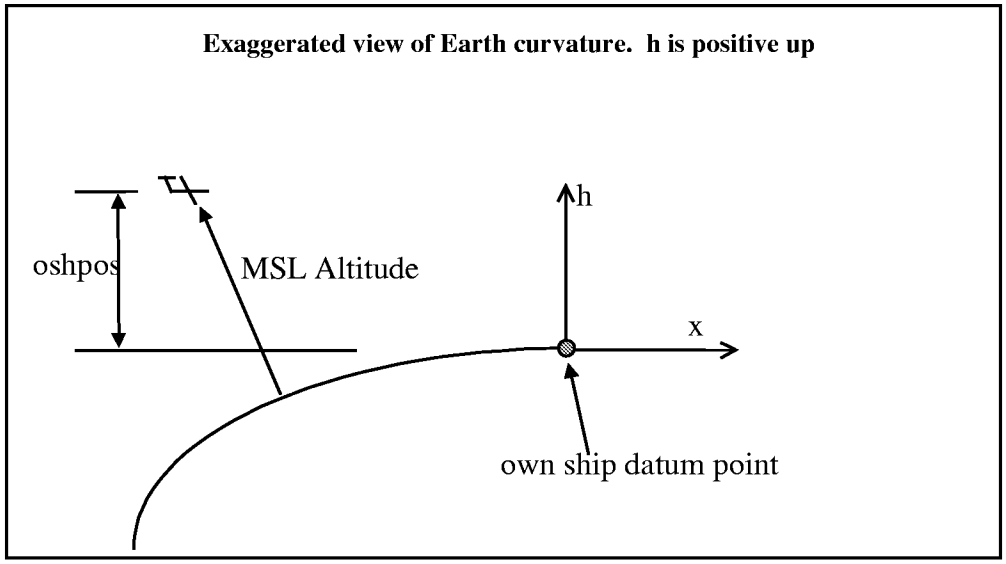

Figure 3.3.1 Side View Of Ails Coordinate System

Figure 3.3.2 shows a "downrange" view of the AILS coordinate system. This is the runway scenario as viewed in the landing direction. The "x" axis in this diagram is positive into the page. The variable ajh_dp_offset is positive as shown.

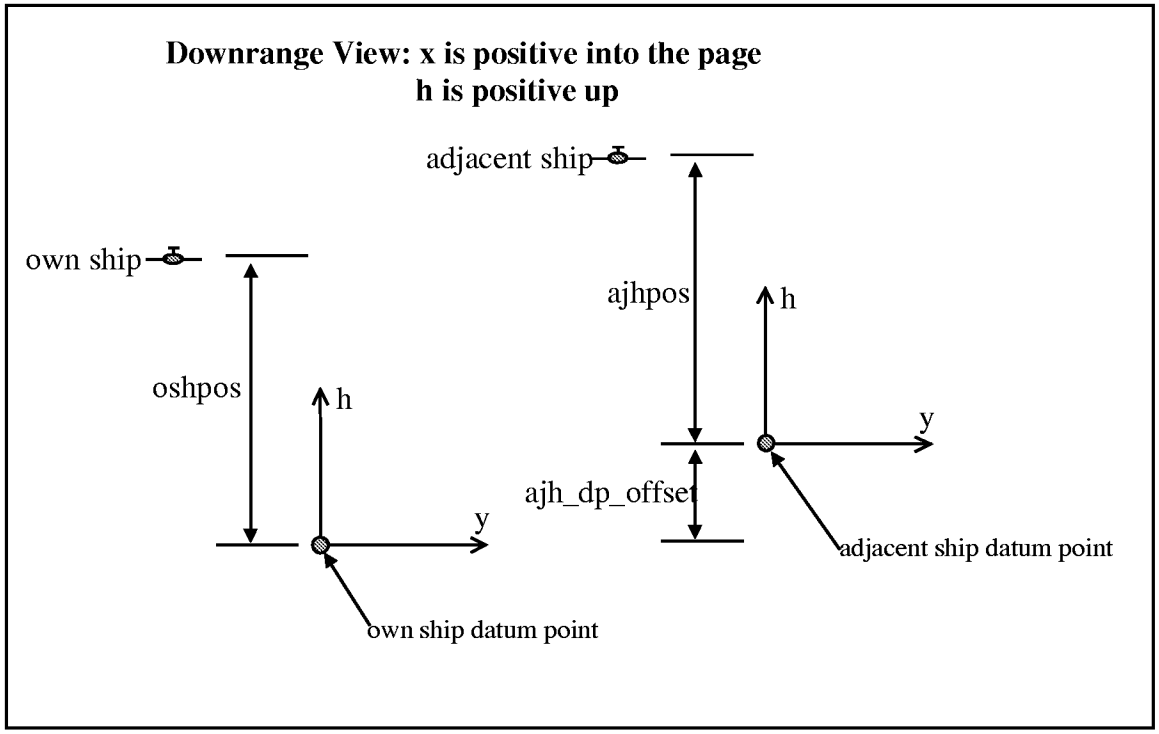

Figure 3.3.2 Downrange View Of Local AILS Coordinates

3.4 Transformation Equations Between Parallel Runway Coordinates

Recall that as AILS performs a threat evaluation of one ship against another, it will choose the intruder's frame of reference as a common frame to work in. Following are the equations that perform the necessary transformations to establish a single coordinate system that corresponds to a particular scenario. Refer back to Figure 3.2.1 on page 15 for the corresponding geometry. The nomenclature convention is that the evader variable is given a "loc" tag (xloc, yloc), while the intruder variable receives a "0" tag (x0,y0).

State Transformations With NO Snapping to Glideslope and Localizer
Scenario 1: The adjacent ship is assumed to be the intruder x0 = ajxpos y0 = ajypos h0 = ajhpos xloc = (osxpos – ajx_dp_offset) * **cos**(ajpsi_offset) + (osypos-ajy_dp_offset) * **sin**(ajpsi_offset) yloc = (osxpos – ajx_dp_offset) * -**sin**(ajpsi_offset) + (osypos-ajy_dp_offset) * **cos**(ajpsi_offset) hloc = oshpos – ajh_dp_offset
Scenario 2: The own ship is assumed to be the intruder x0 = osxpos y0 = osypos h0 = ajhpos ajpsiloc' = -ajpsiloc ajxloc' = ajxloc * **cos**(ajpsiloc) + ajyloc * **sin**(ajpsiloc) ajyloc' = -ajxloc * **sin**(ajpsloc) + ajyloc * **cos**(ajpsiloc) xloc = (ajxpos + ajx_dp_offset') * **cos**(ajpsi_offset') + (ajypos + ajy_dp_offset)'*__sin__(ajpsi_offset') yloc = (ajxpos + ajx_dp_offset') * -**sin**(ajpsi_offset') + (ajypos + ajy_dp_offset)'*__cos__(ajpsi_offset') hloc = ajhpos + ajh_dp_offset

Table 3.4.1 State Variable Transformations With NO Snap

State Transformations With Snapping to Glideslope and Localizer
Scenario 1: The adjacent ship is assumed to be the intruder x0 = ajxpos y0 = ajypos h0 = ajhpos xloc = (osxpos – ajx_dp_offset) * **cos**(ajpsi_offset) + (-ajy_dp_offset) * **sin**(ajpsi_offset) yloc = (osxpos – ajx_dp_offset) * -**sin**(ajpsi_offset) + (-ajy_dp_offset) * **cos**(ajpsi_offset) hloc = -ajh_dp_offset + ostch – osxpos*__tan__(osglide)
Scenario 2: The own ship is assumed to be the intruder x0 = osxpos y0 = osypos h0 = oshpos ajpsiloc' = -ajpsiloc ajxloc' = ajxloc * **cos**(ajpsi_offset) + ajyloc * **sin**(ajpsi_offset) ajyloc' = -ajxloc * **sin**(ajpsi_offset) + ajyloc * **cos**(ajpsi_offset) xloc = (ajxpos + ajx_dp_offset') * **cos**(ajpsi_offset') + (ajy_dp_offset)'*__sin__(ajpsi_offset') yloc = (ajxpos + ajx_dp_offset') * -**sin**(ajpsi_offset') + (ajy_dp_offset)'*__cos__(ajpsi_offset') hloc = ajh_dp_offset + ajtch – ajxpos * **tan** (ajglide)

Table 3.4.2 State Variable Transformations With Snap

The variables introduced above (ajglide, ajtch, osglide, and ostch) are the glideslope angles and threshold crossing heights that define the glidepaths that the aircraft are snapped to. These variables are described further in the following section where the relevance of approach data to the AILS algorithm is discussed.

3.5 Use of Approach Data to Perform Conversion to AILS Coordinates

AILS is confined to a parallel runway approach scenario. Approach data is therefore a vital and integral part of the AILS algorithm. This is especially true since AILS performs "snapping" to glide-slopes and localizers which requires precise knowledge of where the runways and approaches are.

Depending on the specific implementation of AILS, the coordinate transformation from latitude, longitude, and altitude to the local runway coordinate frame requires knowledge of the local runway and approach. The software that performed these conversions for the flight tests used the convention that was defined according to conventions adopted by Honeywell's SLS/GNSSU systems.

Figure 3.5.1 shows the convention adopted by Honeywell's GNSSUs to define a particular approach. The variables used in this convention are equivalent to the key variables used by AILS as it refers to the approach geometry.

The Alerting Path Length (APL), also known as the AILS Path Length, is defined as a linear distance from the runway datum point. When the aircraft is within this distance from the datum point, the AILS algorithm may be turned on. The significance of the APL is that outside of the APL, aircraft are required to maintain 1000 ft vertical separation, whereas once the APL is entered, aircraft may begin to lose the vertical separation. The APL is a system design parameter which typically ranges from 10 to 24 nautical miles, however the selected precision approach system should be a strong determining factor. The APL is discussed further in sections 6 and 6.9 where other criteria for enabling AILS protection is discussed.

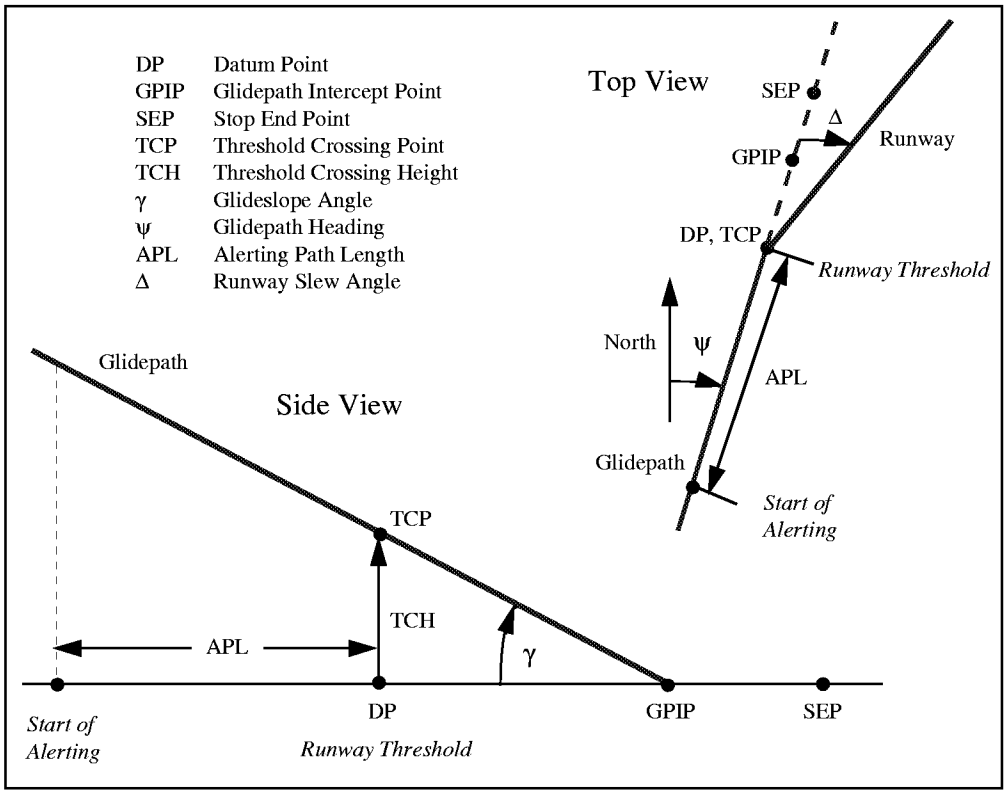

Figure 3.5.1 Key Approach Parameters

Table 3.5.1 below correlates some of the data used to define approaches by the Honeywell SLS format to the internal variables used by AILS.

AILS Variable	Description	Relationship to external approach info
osglide	own ship glide path angle	osglide = gamma (glide path angle) for own ship. Positive as shown in **Figure 3.5.1**. 3 degrees is standard.
ajglide	adjacent ship glide path angle	ajglide = gamma (glide path angle) for adjacent ship. Positive as shown in **Figure 3.5.1**. 3 degrees is standard.
ostch	altitude at which the glide path crosses over the datum point for the own ship	ostch = TCH (Threshold crossing height) for the own ship approach
ajtch	altitude at which the glide path crosses over the datum point for the	ajtch = TCH (Threshold crossing height) for the adjacent ship approach

AILS Variable	Description	Relationship to external approach info
	datum point for the adjacent ship.	
ajx_dp_offset	x offset of adjacent ship datum point from own ship datum point in own ship coordinates.	relative position of adjacent ship datum point (DP) to own ship datum point (DP).
ajy_dp_offset	y offset of adjacent ship datum point from own ship datum point in own ship coordinates.	relative position of adjacent ship datum point (DP) to own ship datum point (DP).
ajh_dp_offset	altitude offset of adjacent ship datum point from own ship datum point in own ship coordinates.	relative position of adjacent ship datum point (DP) to own ship datum point (DP).
ajx_dp_offset'	x offset of adjacent ship datum point from own ship datum point in adjacent ship coordinates.	relative position of adjacent ship datum point to own ship datum point (DP).
ajy_dp_offset'	y offset of adjacent ship datum point from own ship datum point in adjacent ship coordinates.	relative position of adjacent ship datum point to own ship datum point (DP).
ajh_dp_offset'	altitude offset of adjacent ship datum point from own ship datum point in own ship coordinates.	relative position of adjacent ship datum point (DP) to own ship datum point (DP).
ajpsi_offset ajpsi_offset'	angle offset of adjacent ship approach heading relative to own ship approach heading.	determined by the own ship and adjacent ship approach paths. These approach paths are determined by the respective datum points (DP)and their corresponding stop end points (SEP)

Table 3.5.1 Definition Of Key AILS Approach Related Parameters

For these approach parameters, the adjacent ship specific variables marked as "prime" variables (ajx_dp_offset', ajsi_offset' etc), are computed internally by AILS. Detailed knowledge of these prime variables is NOT required. The implementers are required to know how to compute and specify the normal own ship non-"prime" parameters which need to be supplied to the AILS algorithm. Section 5.1.1 further describes input parameter requirements.

4 AILS Top Level Description with Flow Charts

This section first gives a brief top level description of how AILS performs its alert and threat determinations. Then, flowcharts schematically depict the main functional blocks that carry out the AILS algorithm.

4.1 AILS Top Level Description

AILS checks two main scenarios: 1) The adjacent ship as intruder and the own ship as evader; and 2) The own ship as intruder and the adjacent ship as the evader. Also, depending on certain flags passed to the algorithm which determine the aircraft's on-approach/off-approach status, the evader or intruder may be snapped as necessary. In each scenario, the intruders states are projected forward a designated period of time. The intruder's vertical profile is checked against the evader's vertical profile to determine the times that the intruder is inside of the evader's vertical protected region.

The intruder's horizontal states are also projected forward. If the intruder is turning, at each specified interval of the turn, AILS assumes that the intruder levels out of the turn and continues straight in the current direction (AILS fan). The solution of a quadratic equation determines the times at which the intruder enters and exits the evaders protected elliptical zone. These horizontal entry and exit times are compared against the vertical entry and exit times to check if the intruder is ever inside the evader's protected zone within the period of evaluation.

These checks are performed for both the caution and the warning alert levels. The appropriate alerts are issued by flipping appropriate bits in a status vector.

4.2 AILS Algorithm Structure and Flow Charts

This section portrays the basic functional blocks of the current AILS algorithm. Flowcharts are presented, but they do not provide a complete description of the AILS algorithm. Instead their intent is to aid the reader in understanding of the algorithm structure. For a complete and comprehensive algorithm description, refer to the pseudo-code section of this document.

Table 4.2.1 below outlines the major functional blocks of AILS. The flowcharts are presented in a top down fashion starting with Larcalert_full at the top.

Larcalert_Full (Figure 4.2.1) is the top level routine which executes the AILS algorithm. One major functional block of Larcalert_Full is the ilook scenario setup block (Figure 4.2.2). This is responsible for staging the roles of the own ship and the adjacent ship as intruders and evaders. For each role, appropriate variables related to aircraft states and alerting are defined. The ilooks/scenarios block also calls the Chkvert_full routine (Figure 4.2.3) which performs the vertical scenario check of the intruder against the evader's protected zone.

Once the scenario/ilook blocks are complete, the Larcalert_Full executive will sequentially perform the forward projections and fan of one aircraft against the other. The function Chktrack_full (Figure 4.2.4) will be invoked to check for potential intrusions for each tangent track of the fan, while the function Chkrange_full (Figure 4.2.6) will check for any instant intruder-in-evader-ellipse scenarios. Chktrack_Full answers the question: "Will the intruder be

in the evader's elliptical zone at any time of this current tangent track?", whereas the Chkrange_full answers the question "Is the intruder in the evader's elliptical zone right now?"

If Chkrange_Full or Chktrack_Full detect any intrusions, they will raise the appropriate alerting flags that are returned to the outside world through Larcalert_Full.

AILS Routine or Functional Block	Function	Flowchart
Larc_alert_full	Main AILS executive routine. Sets up variables and alerting parameters. Sequences through intrusion scenarios; Calls vertical determination routines; Performs AILS forward projections and fans; calls Chktrack_full and Chkrange_full routines which evaluate threats.	Figure 4.2.1
ilooks block/ scenario setup	This is a major sub-block of larc_alert full. This block sets the stage for the alert checks. It sets states information, alerting parameters, as well as calls Chkvert_full to assess the vertical scenarios.	Figure 4.2.2
Chkvert_full	Assesses vertical situation. Checks to see when intruder aircraft is in the evader's vertical alert threshold.	Figure 4.2.3
Chktrack_full	Performs tangent track check for current time to end of current tangent track to see if the intruder will be in the evader's protected ellipse at any time.	Figure 4.2.4 Figure 4.2.5
Chkrange_full	Performs instantaneous check to see if the intruder is in the evader's horizontal ellipse thresholds.	Figure 4.2.6

Table 4.2.1 AILS Major Functional Blocks and Routines

4.2.1 Larcalert_full Flowchart

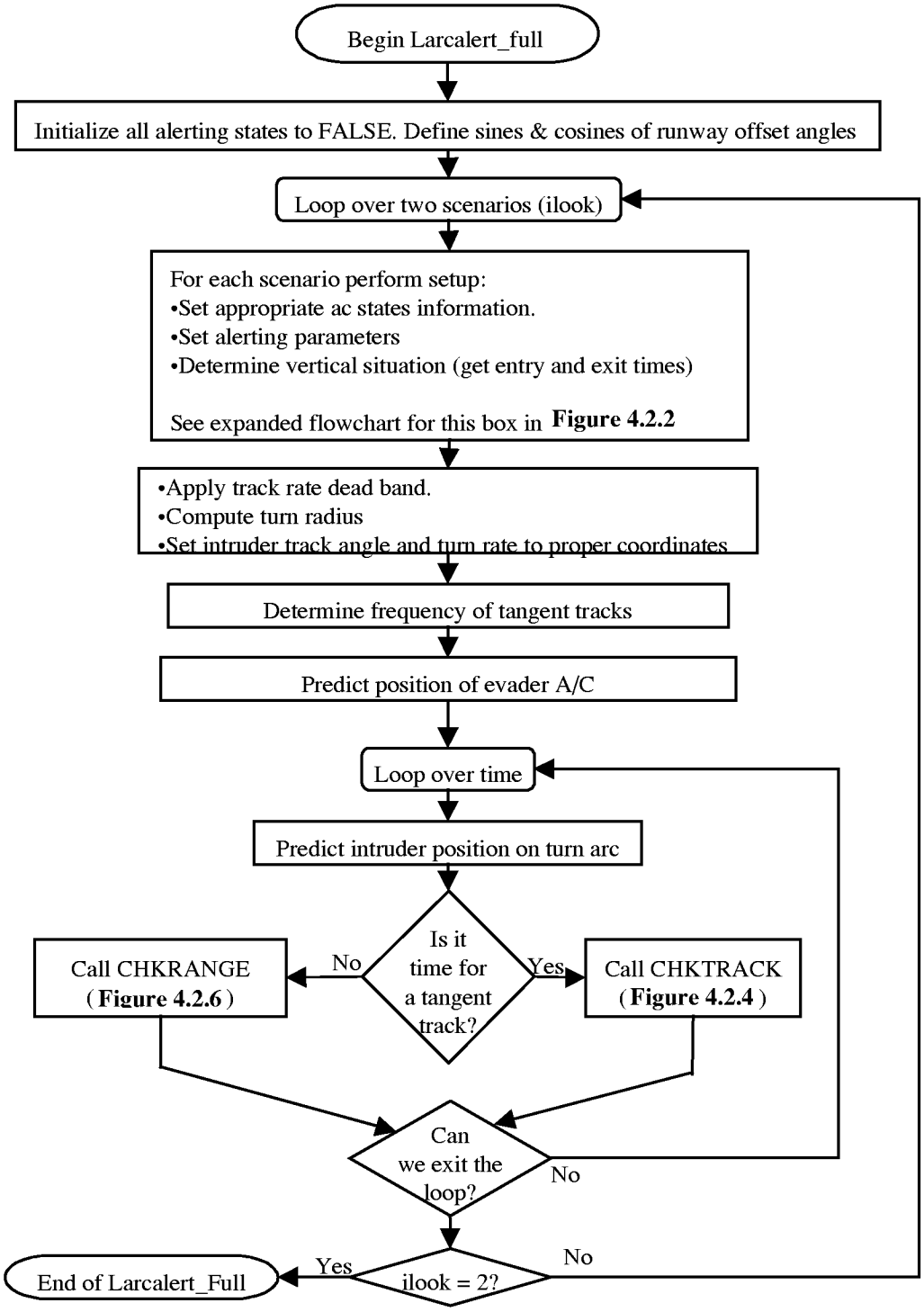

Figure 4.2.1 Larcalert_full Flow Chart

4.2.2 Scenario Setup (ilook blocks) Flowchart

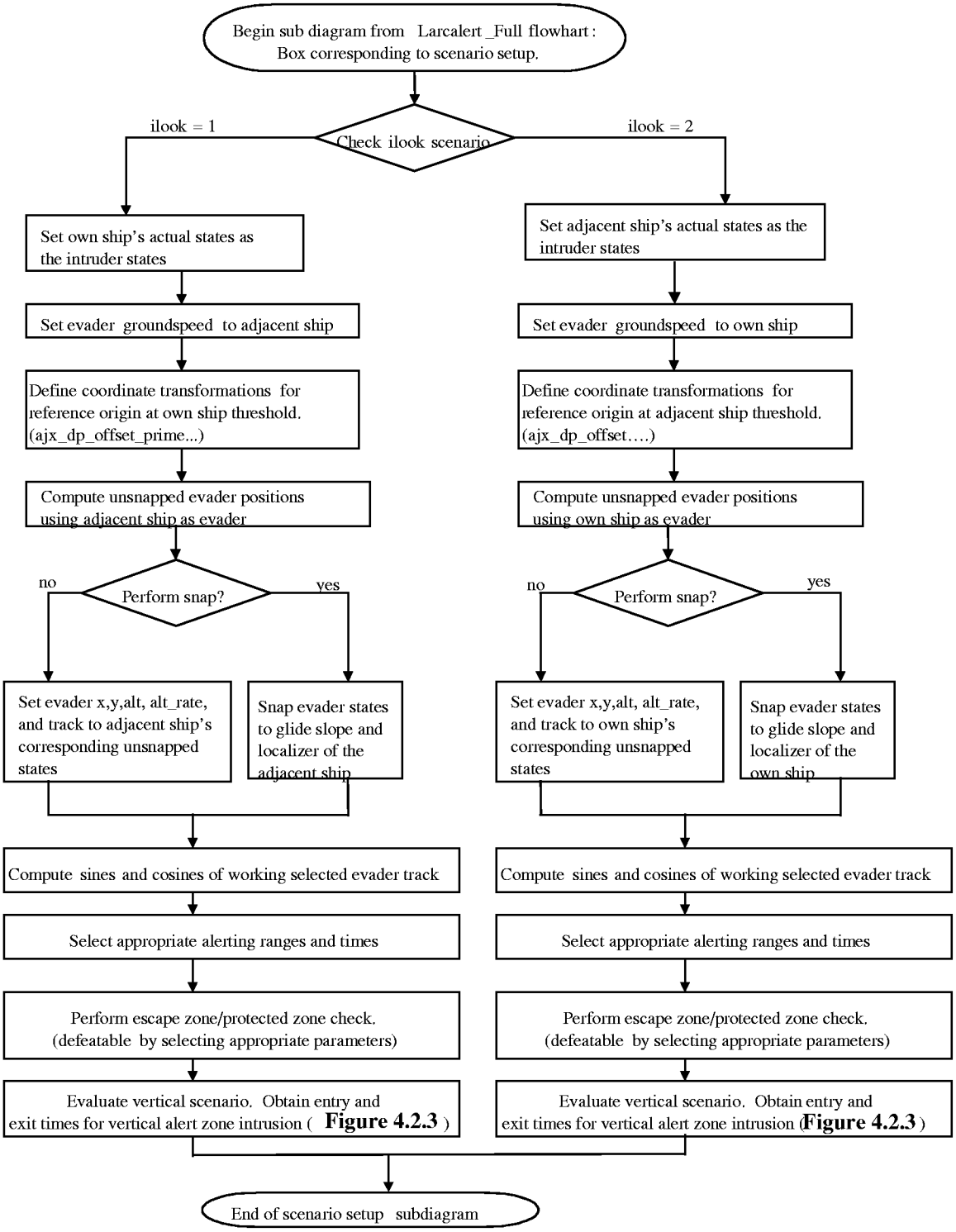

Figure 4.2.2 Scenario Setup (ilook blocks) Flowchart

4.2.3 Chkvert_full Flowchart

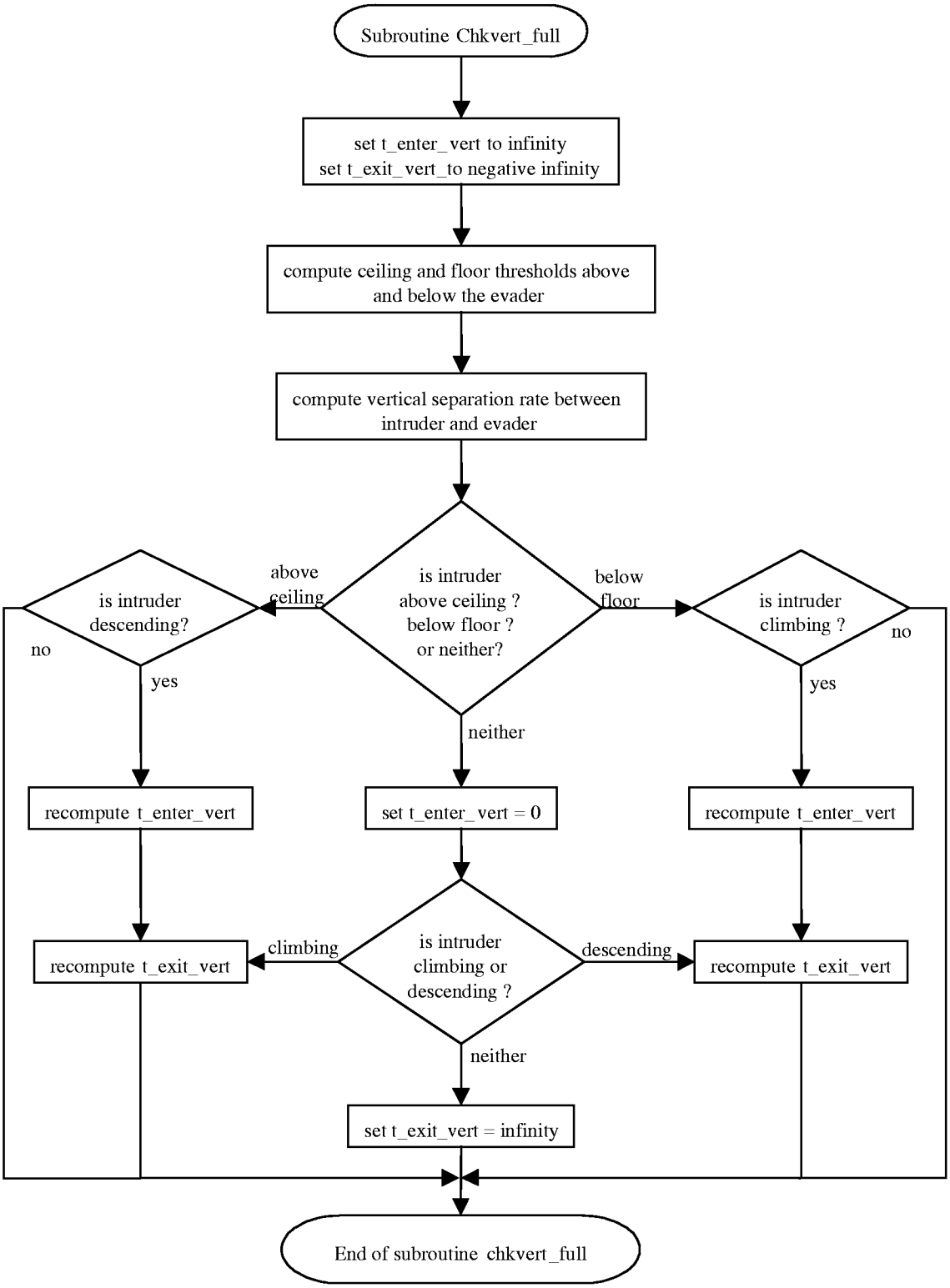

Figure 4.2.3 Chkvert_full Flowchart

4.2.4 Chktrack_full Flowchart

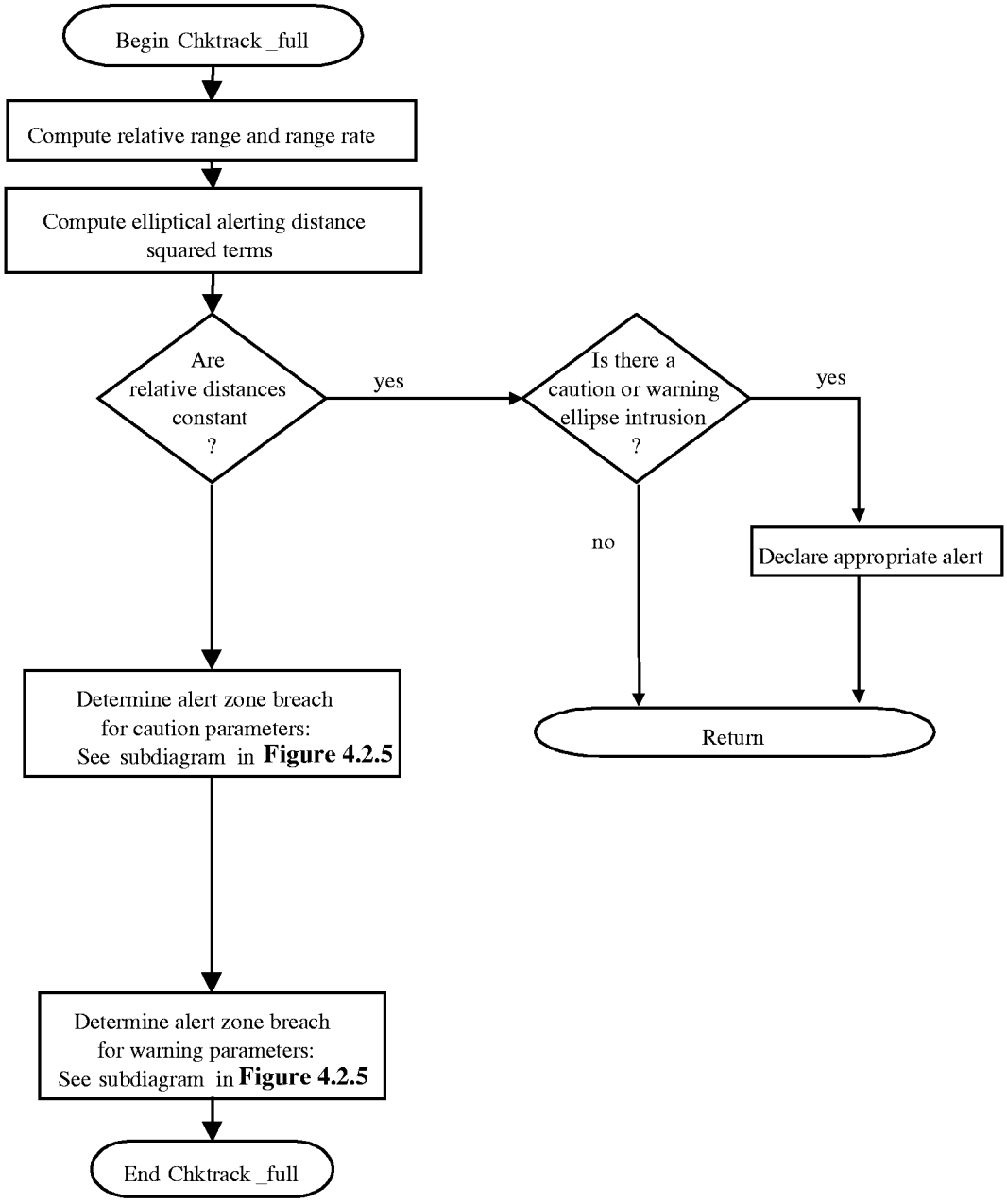

Figure 4.2.4 Chktrack_full Flowchart

4.2.5 Chktrack_full Subdiagram Flowchart

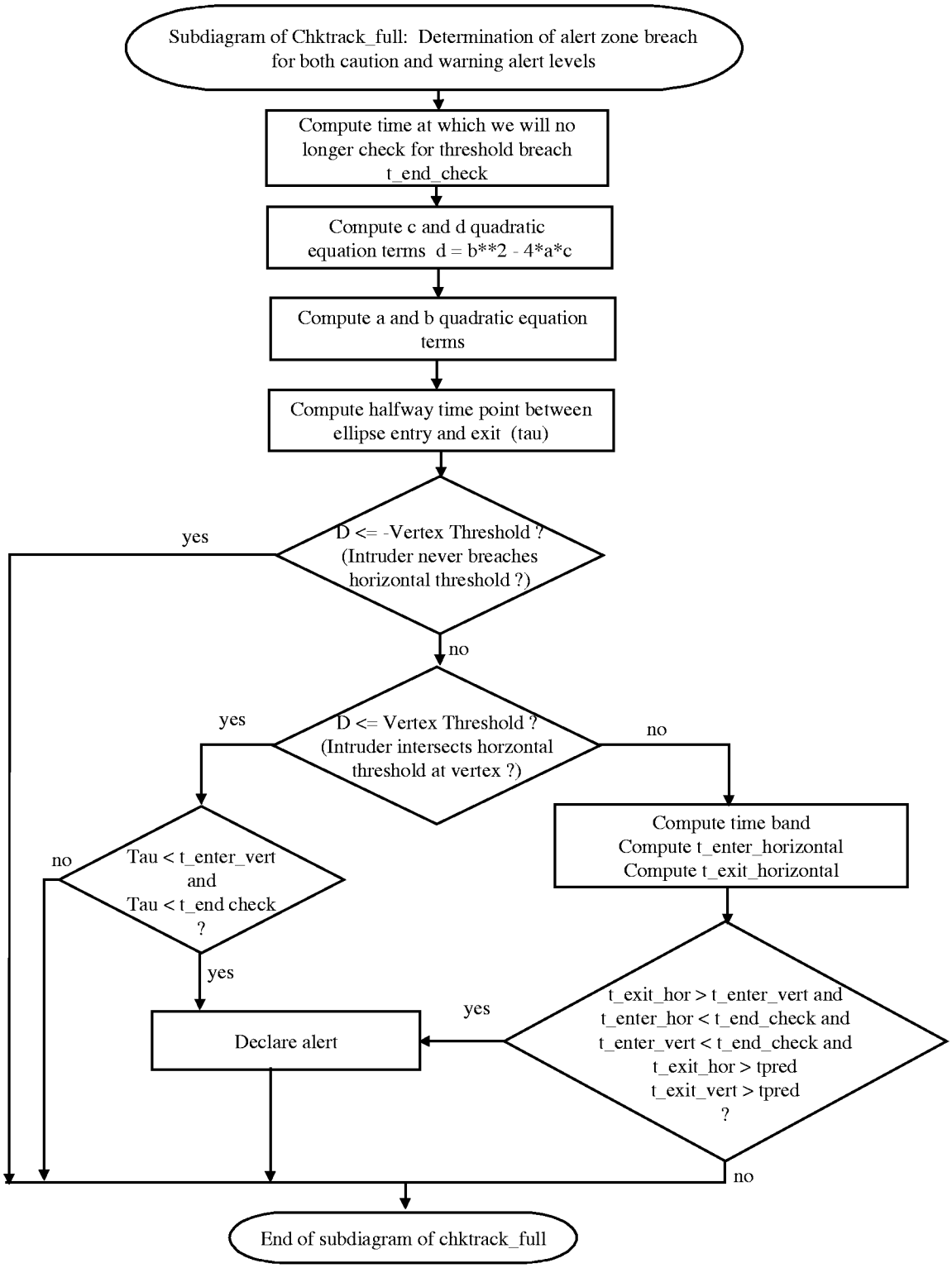

Figure 4.2.5 Subdiagram Chktrack_full flow chart

4.2.6 Chkrange_full Flowchart

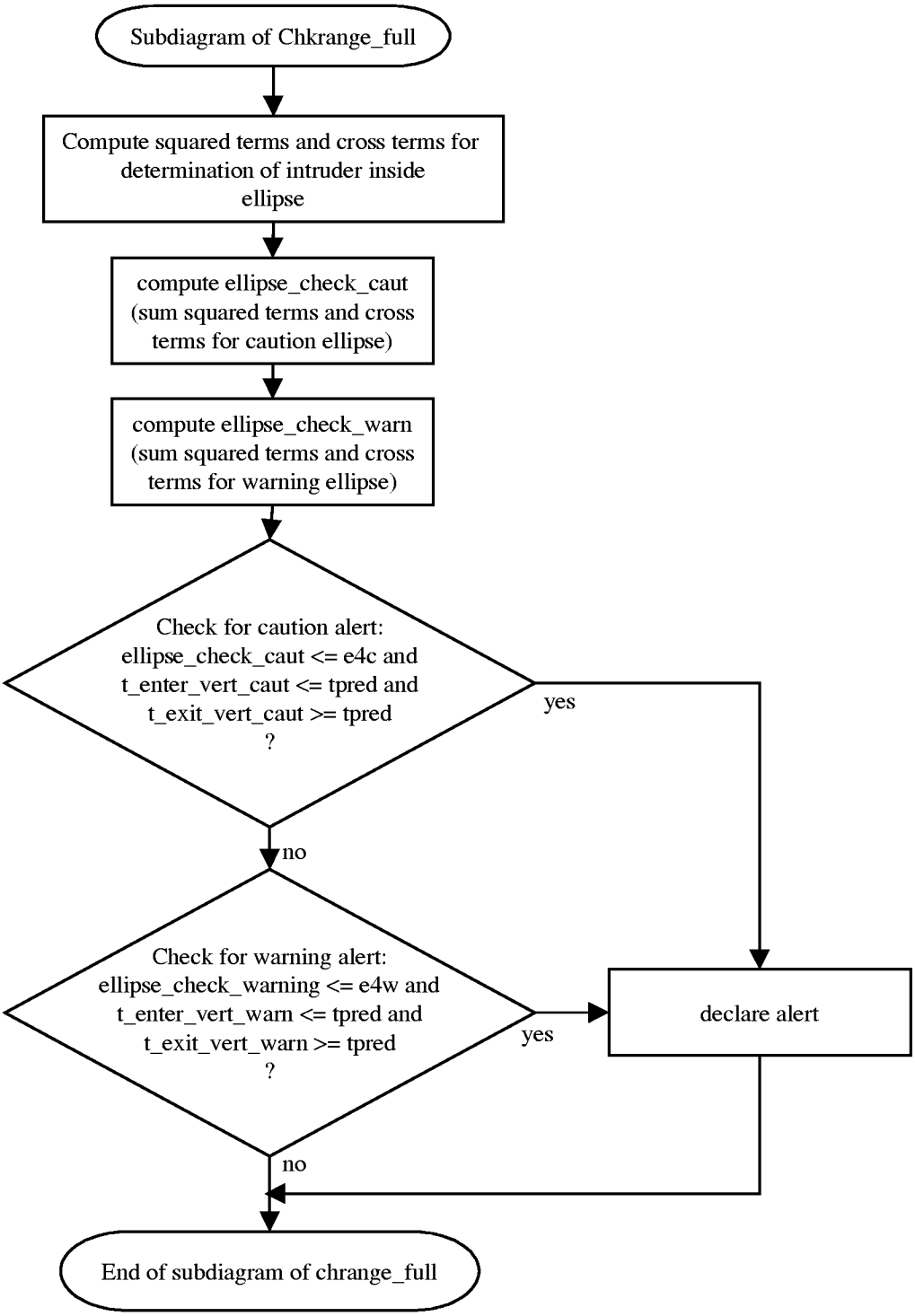

Figure 4.2.6 Chkrange_full flow chart

5 AILS Data and Pseudo Code Descriptions

This section describes the AILS algorithm in detail using a pseudo-code syntax that looks similar to "C". The pseudo-code is described in sections that correspond to modules of software. Each section describes the variables that are input, output, and internal to that section, as well as the pseudo-code that implements that module. Section 5.1 also describes some data that is common to all of the modules.

Some of the conventions used in the pseudo-code are as follows:

=	variable assignment
==	equality test
&&	logical AND
||	logical OR
/* text */	comments
*variable	use pointer to variable
&variable	get pointer to variable

It is recommended that variables defined in the Input/Output Parameters DescriptionTables be coded up as **arguments** and **NOT global variables**. The only global variables coded should be constants or literals defined in Table 5.1.2.

5.1 Larcalert_full and Top Level AILS Descriptions

5.1.1 Larcalert_full/AILS Input/Output Parameters Description

Following is the data dictionary for variables being passed in and out of the larc_alert_full algorithm. All variables are input variables with the exception of the **status** array variable which is an input/output variable.

Variable	Type	Units	Description	Coordinate System
osxpos	double	feet	Own ship downrange position relative to own ship datum point.	os runway
osypos	double	feet	Own ship cross-range position relative to own ship datum point.	os runway
osgs	double	ft/sec	Own ship ground speed.	absolute
ostrk	double	rad	Own ship track angle relative to own ship localizer/approach path centerline.	os runway
ostrkdot	double	rad/sec	Own ship track angle rate relative to own ship localizer/approach path centerline.	os runway
osh	double	ft	Own ship altitude above own ship runway datum point (in runway coordinates).	os runway

Variable	Type	Units	Description	Coordinate System
oshdot	double	ft/sec	Own ship altitude rate in runway coordinates relative to the own ship datum point.	os runway
osglide	double	rad	Own ship glide path angle. Defined by approach information (typically corresponds to approximately + 3 degrees for standard approach)	see Table 3.5.1
ostch	double	ft	Own ship threshold crossing height.	see Table 3.5.1
ajxpos	double	feet	Adjacent ship downrange position relative to adjacent ship runway threshold	aj runway
ajypos	double	feet	Adjacent ship cross-range position relative to adjacent ship runway threshold	aj runway
ajgs	double	ft/sec	Adjacent ship ground speed.	absolute
ajtrk	double	rad	Adjacent ship track angle relative to the adjacent ship localizer/approach path centerline.	aj runway
ajtrkdot	double	rad/sec	Adjacent ship track angle rate relative to the adjacent ship localizer/approach path centerline.	aj runway
ajh	double	ft	Adjacent ship altitude above adjacent ship runway datum point (in runway coordinates).	aj runway
ajhdot	double	ft/sec	Adjacent ship altitude rate in runway coordinates relative to the adjacent ship datum point.	aj runway
ajglide	double	rad	Adjacent ship glide path angle. Defined by approach information (typically corresponds to approximately + 3 degrees for standard approach)	see Table 3.5.1
ajtch	double	ft	Adjacent ship threshold crossing height.	see Table 3.5.1
ajx_dp_offset	double	ft	x offset of aj runway datum point from os runway datum point (in os coordinate system)	see Table 3.2.1
ajy_dp_offset	double	ft	y offset of aj runway datum point from os runway datum point (in os coordinate system)	see Table 3.2.1
ajh_dp_offset	double	ft	z offset of aj runway datum point from os runway datum point (in os coordinate system)	see Table 3.2.1

Variable	Type	Units	Description	Coordinate System
ajpsi_ offset	double	rad	Angle offset of adjacent runway approach path from the own runway approach path	see Table 3.2.1
aldst_e[10]	double	ft	Elliptical alert range threshold vector	
alvup[5]	double	ft	Vertical alert range threshold above evader vector.	
alvdown[5]	double	ft	Vertical alert range threshold below evader vector	
altime[5]	double	ft	Alert time threshold vector	
protected_ esc[5]	double	ft	Protected escape zone vector parameters	
trkratedb	double	rad/se c	Track rate deadband	
turntime	double	sec	Time duration with which to allow AILS to project the current forward turn.	
tstep	double	sec	Time step search granularity for AILS fan.	
status[100]	int		Vector containing alerting routine status as well as other miscellaneous information.	
os_snap_ flag	int		Flag indicating that AILS should perform snap of the own ship to the own ship's approach path. If TRUE, snap; If FALSE, use actual states of the own ship when checking for the adjacent ship intrusion on the own ship.	
aj_snap_ flag	int		Flag indicating that AILS should perform snap of the adjacent ship to the adjacent ship's approach path. If TRUE, snap; If FALSE, use actual states for the adjacent ship when checking for the own ship intrusion on the adjacent ship.	

Table 5.1.1 Larcalert_full/AILS Input Output Variables Data Dictionary

5.1.2 AILS Literals and Indices

The following class of variables are indices or literals that are used to access array elements within the AILS algorithm. In a "C" language implementation they would be defined through the use of the "C" "#define" statements. In Ada or other languages they could be either

integers or enumerated types. In our application they are used to show how to access specific array data elements. Those elements are subsequently defined in the next data dictionary section.

INDEX/ LITERAL	Definition
LEVEL_1	1
LEVEL_2	2
LEVEL_3	3
LEVEL_4	4
PROTECTED_ESC_LEV_3	5
PROTECTED_ESC_LEV_4	6
LEVEL_1_DOWNRANGE	1
LEVEL_1_CROSSRANGE	2
LEVEL_2_DOWNRANGE	3
LEVEL_2_CROSSRANGE	4
LEVEL_3_DOWNRANGE	5
LEVEL_3_CROSSRANGE	6
LEVEL_4_DOWNRANGE	7
LEVEL_4_CROSSRANGE	8
LATERAL	0
AHEAD	1
BEHIND	2
ABOVE	3
BELOW	4

Table 5.1.2 AILS Indices and Literals Specifcations

5.1.3 AILS Array Element Descriptions

The following data dictionary describes the individual elements of the special arrays used to handle AILS data.

variable(element)	Description	Definition/Notes
status[LEVEL_1]	level 1 alert status: ownship ship intruding at the adjacdent ship: caution alert.	0 = no alert 1 = alert tripped
status[LEVEL_2]	level 2 alert status: adjacent ship intruding at the own ship: caution alert.	0 = no alert 1 = alert tripped
status[LEVEL_3]	level 3 alert status: own ship intruding at the adjacent ship: warning alert.	0 = no alert 1 = alert tripped
status[LEVEL_4]	level 4 alert status: adjacent ship intruding at the own ship: warning alert.	0 = no alert 1 = alert tripped
status[PROTECTED_ESC_ LEV_3]	protected escape zone alert status. If TRUE, the ownship is in the adjacent ship's protected escape zone	0 = no alert 1 = alert tripped
status[PROTECTED_ESC_ LEV_4]	protected escape zone alert status. If TRUE, the adjacent ship is in the own ship's protected escape zone	0 = no alert 1 = alert tripped
aldst_e[LEVEL_1_DOWNRANGE]	elliptical downrange alerting parameter for level 1	feet
aldst_e[LEVEL_1_CROSSRANGE]	elliptical cross-range alerting parameter for level 1	feet
aldst_e[LEVEL_2_DOWNRANGE]	elliptical downrange alerting parameter for level 2	feet
aldst_e[LEVEL_2_CROSSRANGE]	elliptical cross-range alerting parameter for level 2	feet
aldst_e[LEVEL_3_DOWNRANGE]	elliptical downrange alerting parameter for level 3	feet
aldst_e[LEVEL_3_CROSSRANGE]	elliptical cross-range alerting parameter for level 3	feet
aldst_e[LEVEL_4_DOWNRANGE]	elliptical downrange alerting parameter for level 4	feet

variable(element)	Description	Definition/Notes
	parameter for level 4	
aldst_e[LEVEL_4_CROSSRANGE]	elliptical cross-range alerting parameter for level 4	feet
alvup[LEVEL_1]	vertical alerting threshold distance above for level 1	feet
alvup[LEVEL_2]	vertical alerting threshold distance above for level 2	feet
alvup[LEVEL_3]	vertical alerting threshold distance above for level 3	feet
alvup[LEVEL_4]	vertical alerting threshold distance above for level 4	feet
alvdown[LEVEL_1]	vertical alerting threshold distance below for level 1	feet
alvdown[LEVEL_2]	vertical alerting threshold distance below for level 2	feet
alvdown[LEVEL_3]	vertical alerting threshold distance below for level 3	feet
alvdown[LEVEL_4]	vertical alerting threshold distance below for level 4	feet
altime[LEVEL_1]	alert time threshold for level 1	sec
altime[LEVEL_2]	alert time threshold for level 2	sec
altime[LEVEL_3]	alert time threshold for level 3	sec
altime[LEVEL_4]	alert time threshold for level 4	sec
protected_esc[LATERAL]	lateral protected escape zone	ft
protected_esc[AHEAD]	ahead protected escape zone	ft
protected_esc[BEHIND]	behind protected escape zone	ft
protected_esc[ABOVE]	above protected escape zone	ft
protected_esc[BELOW]	below protected escape zone	ft

Table 5.1.3 AILS Array Element Descriptions

5.1.4 Larcalert_full Local Internal Variables Data Dictionary

Variable	Type	Units	Description	Coordinate System
actrk	double	rad	heading of the pursuer aircraft	intruder
arcrad	double	rad	turn radius of pursuer aircraft at the current bank angle or turn rate.	
dttrk	double	sec	time between tangent tracks	
gs	double	ft/sec	ground speed of pursuer aircraft	
gsloc	double	sec	ground speed of evader aircraft	
idtrk	int		number of time steps between tangent tracks	
maxstep	int		maximum number of time steps before the maximum alert time **altime** is exceeded.	
tantrk	double	rad	heading of tangent track	pursuer
tpred	double	sec	time allotted for forward prediction of current states	
trk	double	rad	heading of pursuer aircraft	pursuer
trkrate	double	rad/sec	turn rate of pursuer aircraft	pursuer
trkdot	double	rad/sec	= -trkrate	
xloc	double	feet	x position of evader aircraft	pursuer
yloc	double	feet	y position of evader aircraft	pursuer
trkloc	double	rad	track angle of evader aircraft	pursuer
zloc	double	ft	altitude of pursuer airraft	pursuer
zlocdot	double	ft/sec	altitude rate of pursuer aircraft	pursuer
x0	double	ft	x position of pursuer aircraft	pursuer
y0	double	ft	y position of pursuer aircraft	pursuer
xtrk	double	ft	x position along arc, start of tangent track	pursuer

Variable	Type	Units	Description	Coordinate System
ytrk	double	ft	y position along alrc, start of tangent track	pursuer
COStrk	double	ft	cosine of track angle of pursuer aircraft	
SINtrk	double	ft	sine of track angle of the pursuer aircraft	
t_enter_vert_caut	double	sec	time at which the pursuer will enter the evader's vertical protected threshold: caution level	
t_enter_vert_warn	double	sec	time at which the pursuer will enter the evader's vertical protected threshold: warning level	
t_exit_vert_caut	double	sec	time at which the pursuer will exit the evader's vertical protected threshold: caution level	
t_exit_vert_warn	double	sec	time at which the pursuer will exit the evader's vertical protected threshold: warning level	
xlocpos[]	double	ft	array of x positions of evader aircraft	
ylocpos[]	double	ft	array of y positions of evader aircraft	
z0	double	ft	altitude of pursuer aircraft	pursuer
z0dot	double	ft/sec	altitude rate of pursuer aircraft	pursuer
ctime	double	sec	states project-ahead time for determining caution alert	
wtime	double	sec	states project-ahead time for determining warning alert	
vflag[]	int		flag indicating potential for vertical threshold puncture. This flag is an output of the **chkvert** routine and is not currently used for anything	
ilook	int		program loop control flag ilook = 1: own ship is the pursuer ilook = 2: adjacent ship is pursuer	
cbit	int		indice used to indicate access status to caution array	

Variable	Type	Units	Description	Coordinate System
wbit	int		indice used to indicate access status to warning array	
i	int		loop index	
iarc	int		loop index (used during fan arc)	
trkrate_adjusted	double	rad	adjusted track rate	
ajx_dp_offset_prime	double	ft	ownship datum point x offset in the adjacent ship coordinate frame	adjacent ship
ajy_dp_offset_prime	double	ft	ownship datum point y offset in the adjacent ship coordinate frame	adjacent ship
sin_ajpsi_offset	double	rad	sin of adjacent ship runway (approach path) offset angle to own ship runway	
cos_ajpsi_offset	double	rad	cos of adjacent ship runway (approach path) offset angle to own ship runway	
ajpsi_offset_prime	double	rad	negative of adjacent ship runway (approach path) offset to own ship approach path	
sin_ajpsi_offset_prime	double	rad	sin of ajpsi_offset_prime	
cos_ajpsi_offset_prime	double	rad	cos of ajpsi_offset_prime	
xloc_unsnapped	double	ft	unsnapped x position of evader aircraft	intruder
yloc_unsnapped	double	ft	unsnapped y position of evader aircraft	intruder
zloc_unsnapped	double	ft	unsnapped z position of evader aircraft	intruder
sin_trkloc	double		sin of evader track angle: sin(trkloc)	
cos_trkloc	double		cos of evader track angle : cos(trkloc)	
e1c	double		e1 coefficient for rotated caution ellipse	
e2c	double		e2 coefficient for rotated caution ellipse	
e3c	double		e3 coefficient for rotated caution ellipse	

Variable	Type	Units	Description	Coordinate System
e4c	double		e4 coefficient for rotated caution ellipse	
e1w	double		e1 coefficient for rotated warning ellipse	
e2w	double		e2 coefficient for rotated warning ellipse	
e3w	double		e3 coefficient for rotated warning ellipse	
e4w	double		e4 coefficient for rotated warning ellipse	
sin_trkloc_sqrd	double		sin of evader track squared	
cos_trkloc_sqrd	double		cos of evader track squared	
cdist_downrange_sqrd	double		caution downrange ellipse parameter squared	
wdist_downrange_sqrd	double		warning downrange ellipse parameter squared	
cdist_crossrrange_sqrd	double		caution cross-range ellipse parameter squared	
wdist_crossrrange_sqrd	double		warning cross-range ellipse parameter squared	

Table 5.1.4 AILS Local Variable Data Dictionary

5.1.5 Larcalert_full (AILS Executive) Algorithm Pseudo Code

Begin Larcalert_Full

/* Reset alert strings and flags */
status[LEVEL_1] = FALSE
status[LEVEL_2] = FALSE
status[LEVEL_3] = FALSE
status[LEVEL_4] = FALSE
status[PROTECTED_ESC_LEV_3] = FALSE

```
status[PROTECTED_ESC_LEV_4] = FALSE

/* define sines and cosines of runway offset rotation angles */
sin_ajpsi_offset = sin(ajpsi_offset)
cos_ajpsi_offset = cos(ajpsi_offset)
ajpsi_offset_prime = -ajpsi_offset
sin_ajpsi_offset_prime = -sin_ajpsi_offset
cos_ajpsi_offset_prime = cos_ajpsi_offset

/* loop over the two scenarios, 1 = Ownship intruder 2 = Adjacent ship intruder */
for (ilook = 1 ; ilook <=2 ; ilook++) {
   if (ilook == 1) {
        /* On ilook = 1 first-pass, initialize for OS is intruder AJ is evader */
        /* Set intruder parameters.  Ownship is intruder */
        actrk  = ostrk
        trkrate = ostrkdot
        x0     = osxpos
        y0     = osypos
        h0     = oshpos
        gs     = osgs
        h0dot  = oshdot

        /* perform evader coordinate transformations.  Get evader parameters */
        /* In this pass, evader positions are based on adjacent ship */
        gsloc  = ajgs

        ajx_dp_offset_prime = cos_ajpsi_offset * ajx_dp_offset +
                              sin_ajpsi_offset * ajy_dp_offset
        ajy_dp_offset_prime = -sin_ajpsi_offset * ajx_dp_offset +
                              cos_ajpsi_offset * ajy_dp_offset


        /* Compute unsnapped evader positions. Perform regardless of snapping */
        /*  because we need these values to evaluate protected zones          */
        xloc_unsnapped = cos_ajpsi_offset_prime*(ajxpos+ajx_dp_offset_prime) +
              sin_ajpsi_offset_prime*(ajypos + ajy_dp_offset_prime)
        yloc_unsnapped = -sin_ajpsi_offset_prime*(ajxpos+ajx_dp_offset_prime)+
               cos_ajpsi_offset_prime*(ajypos + ajy_dp_offset_prime)
        hloc_unsnapped = ajhpos + ajh_dp_offset

        /* logic whether or not to snap evader */
        if (aj_snap_flag == FALSE) { /* no snap to glidepath and localizer */
          hloc   = ajhpos + ajh_dp_offset
          hlocdot= ajhdot
          trkloc = ajtrk + ajpsi_offset_prime
          xloc = xloc_unsnapped
          yloc = yloc_unsnapped
```

```
} else  {
 /* snap to glidespath and localizer */
 /* assume threshold location 1000 ft from gpip */
 hloc   =  ajh_dp_offset + ajtch - ajxpos * tan(ajglide)
 hlocdot= -gsloc * tan(ajglide)
 trkloc = ajpsi_offset_prime
 xloc = cos_ajpsi_offset_prime*(ajxpos+ajx_dp_offset_prime) +
     sin_ajpsi_offset_prime*ajy_dp_offset_prime
 yloc = -sin_ajpsi_offset_prime*(ajxpos+ajx_dp_offset_prime)+
      cos_ajpsi_offset_prime*ajy_dp_offset_prime
}
/* trkloc's snapped/unsnapped status is dependent on snap_flag */
sin_trkloc = sin(trkloc)
cos_trkloc = cos(trkloc)
sin_trkloc_sqrd = sin_trkloc * sin_trkloc
cos_trkloc_sqrd = cos_trkloc * cos_trkloc

/* set elliptical alerting parameters */
cdist_downrange_sqrd = aldst_e[LEVEL_1_DOWNRANGE] *
                       aldst_e[LEVEL_1_DOWNRANGE]
cdist_crossrange_sqrd = aldst_e[LEVEL_1_CROSSRANGE] *
                       aldst_e[LEVEL_1_CROSSRANGE]
wdist_downrange_sqrd = aldst_e[LEVEL_3_DOWNRANGE] *
                       aldst_e[LEVEL_3_DOWNRANGE]
wdist_crossrange_sqrd = aldst_e[LEVEL_3_CROSSRANGE] *
                       aldst_e[LEVEL_3_CROSSRANGE]

e4c = cdist_downrange_sqrd * cdist_crossrange_sqrd
e4w = wdist_downrange_sqrd * wdist_crossrange_sqrd

e1c = (cdist_downrange_sqrd*sin_trkloc_sqrd + cdist_crossrange_sqrd*cos_trkloc_sqrd)
e2c = (cdist_downrange_sqrd-cdist_crossrange_sqrd)*2.0*cos_trkloc*sin_trkloc
e3c = (cdist_downrange_sqrd*cos_trkloc_sqrd + cdist_crossrange_sqrd*sin_trkloc_sqrd)

e1w = (wdist_downrange_sqrd*sin_trkloc_sqrd +
                wdist_crossrange_sqrd*cos_trkloc_sqrd)
e2w = (wdist_downrange_sqrd-wdist_crossrange_sqrd)*2.0*cos_trkloc*sin_trkloc
e3w = (wdist_downrange_sqrd*cos_trkloc_sqrd +
                wdist_crossrange_sqrd*sin_trkloc_sqrd)

/* set alerting times */
ctime  = altime[LEVEL_1]
wtime  = altime[LEVEL_3]
cbit   = LEVEL_1
wbit   = LEVEL_3

/* Check for esc zone  violation of adjacent ship */
```

```
        /* Perform this here because  ownship coordinate system is available */
         if  ((xloc_unsnapped < osxpos + protected_esc[AHEAD]) &&
              (xloc_unsnapped > osxpos - protected_esc[BEHIND]) &&
              (hloc_unsnapped < oshpos + protected_esc[ABOVE])  &&
              (hloc_unsnapped > oshpos - protected_esc[BELOW])) {

            if (ajy_dp_offset > 0.0) {  /* The adjacent ship runway is on the right */
                if (yloc_unsnapped < (osypos+protected_esc[LATERAL])) {
                   status[LEVEL_4] = TRUE
                   status[PROTECTED_ESC_LEV_4] = TRUE
                }
            } else if (ajy_dp_offset < 0.0) { /*The adjacent ship runway is on the left*/
                if (yloc_unsnapped > (osypos-protected_esc[LATERAL])) {
                    status[LEVEL_4] = TRUE
                    status[PROTECTED_ESC_LEV_4] = TRUE
                }
            }
        }



        /* Get caution vertical alerting threshold status and times */
        chkvert_full(hloc,hlocdot, h0, h0dot, alvup[1], alvdown[1],
              &t_enter_vert_caut, &t_exit_vert_caut, &vflag[1])

        /* Get warning vertical alerting threshold status and times */
        chkvert_full(hloc,hlocdot, h0, h0dot, alvup[3], alvdown[3],
              &t_enter_vert_warn, &t_exit_vert_warn, &vflag[3])

    } else {
        /* On ilook = 2, 2nd pass, initialize for AJ is intruder OS is evader */
        /* Set intruder parameters */
        actrk  = ajtrk
        trkrate = ajtrkdot
        x0     = ajxpos
        y0     = ajypos
        h0     = ajhpos
        gs     = ajgs
        h0dot  = ajhdot

        /* Perform evader coordinate transformations.  Compute evader parameters */
        /* In this pass, use own ship as evader */
        gsloc  = osgs

        /* Compute unsnapped evader positions. Perform regardless of snapping */
        /*  because we need these values to evaluate protected zones.        */
        xloc_unsnapped   = cos_ajpsi_offset * (osxpos-ajx_dp_offset) +
```

```
   sin_ajpsi_offset * (osypos-ajy_dp_offset)
yloc_unsnapped   = -sin_ajpsi_offset * (osxpos-ajx_dp_offset) +
   cos_ajpsi_offset * (osypos-ajy_dp_offset)
hloc_unsnapped = oshpos

/* logic whether or not to snap evader */
if (os_snap_flag == FALSE) { /* no snap to glidepath and localizer */
  hloc   = oshpos - ajh_dp_offset
  hlocdot= oshdot
  trkloc = ostrk + ajpsi_offset
  xloc = xloc_unsnapped
  yloc = yloc_unsnapped
} else      {
  /* snap to glidepath and localizer */
  /* assume threshold location 1000 ft from gpip */
  hloc   = -ajh_dp_offset + ostch - osxpos*tan(osglide)
  hlocdot= -osgs * tan(osglide)
  trkloc = ajpsi_offset
  xloc   = cos_ajpsi_offset * (osxpos-ajx_dp_offset) +
           sin_ajpsi_offset * (-ajy_dp_offset)
  yloc   = -sin_ajpsi_offset * (osxpos-ajx_dp_offset) +
           cos_ajpsi_offset * (-ajy_dp_offset)
}
/* trkloc's snapped/unsnapped status is dependent on snap_flag */
sin_trkloc = sin(trkloc)
cos_trkloc = cos(trkloc)
sin_trkloc_sqrd = sin_trkloc * sin_trkloc
cos_trkloc_sqrd = cos_trkloc * cos_trkloc

/* set elliptical alerting parameters */
cdist_downrange_sqrd = aldst_e[LEVEL_2_DOWNRANGE] *
                                   aldst_e[LEVEL_2_DOWNRANGE]
cdist_crossrange_sqrd = aldst_e[LEVEL_2_CROSSRANGE] *
                                   aldst_e[LEVEL_2_CROSSRANGE]
wdist_downrange_sqrd = aldst_e[LEVEL_4_DOWNRANGE] *
                                   aldst_e[LEVEL_4_DOWNRANGE]
wdist_crossrange_sqrd = aldst_e[LEVEL_4_CROSSRANGE] *
                                   aldst_e[LEVEL_4_CROSSRANGE]

e4c = cdist_downrange_sqrd * cdist_crossrange_sqrd
e4w = wdist_downrange_sqrd * wdist_crossrange_sqrd

e1c = (cdist_downrange_sqrd*sin_trkloc_sqrd + cdist_crossrange_sqrd*cos_trkloc_sqrd)
e2c = (cdist_downrange_sqrd-cdist_crossrange_sqrd)*2.0*cos_trkloc*sin_trkloc
e3c = (cdist_downrange_sqrd*cos_trkloc_sqrd + cdist_crossrange_sqrd*sin_trkloc_sqrd)

e1w = (wdist_downrange_sqrd*sin_trkloc_sqrd +
```

```
                                wdist_crossrange_sqrd*cos_trkloc_sqrd)
    e2w = (wdist_downrange_sqrd-wdist_crossrange_sqrd)*2.0*cos_trkloc*sin_trkloc
    e3w = (wdist_downrange_sqrd*cos_trkloc_sqrd +
                                wdist_crossrange_sqrd*sin_trkloc_sqrd)

    /* set alerting times */
    ctime  = altime[LEVEL_2]
    wtime  = altime[LEVEL_4]
    cbit   = LEVEL_2
    wbit   = LEVEL_4

    /* Check for protected_esc  violation of own ship */
    /* Perform this here because adjacent ship coordinate system is available */
     if  ((xloc_unsnapped < ajxpos + protected_esc[AHEAD]) &&
          (xloc_unsnapped > ajxpos - protected_esc[BEHIND]) &&
          (hloc_unsnapped < ajhpos + protected_esc[ABOVE])  &&
          (hloc_unsnapped > ajhpos - protected_esc[BELOW])) {

        if (ajy_dp_offset > 0.0) {/* The ownship ship runway is on the left */
             if (yloc_unsnapped > (ajypos-protected_esc[LATERAL])) {
                 status[LEVEL_3] = TRUE
                 status[PROTECTED_ESC_LEV_3] = TRUE
             }
        }  else if (ajy_dp_offset < 0.0) {/*The ownship ship runway is on the right*/
             if (yloc_unsnapped < (ajypos+protected_esc[LATERAL])) {
               status[LEVEL_3] = TRUE
               status[PROTECTED_ESC_LEV_3] = TRUE
             }
        }
     }

    /* Get caution alerting threshold status and times */
    chkvert_full(hloc,hlocdot, h0, h0dot, alvup[2], alvdown[2],
          &t_enter_vert_caut, &t_exit_vert_caut, &vflag[2])

    /* Get warning alerting threshold status and times */
    chkvert_full(hloc,hlocdot, h0, h0dot, alvup[4], alvdown[4],
          &t_enter_vert_warn, &t_exit_vert_warn, &vflag[4])

 }  /* End of ilook initialization block */


 /* The following section deals with the intruder turn/turn rate profile */
 /* Use track rate to determine turn rate */

/* Apply track rate dead band if necessary */
 if (fabs(trkrate) < trkratedb) {
```

```
  /* Bank angle deadband */
   arcrad  = 10000000000.0
   trkrate_adjusted = 0.0
} else {
   trkrate_adjusted = trkrate
   arcrad = gs/trkrate_adjusted
   arcrad  = fabs(arcrad)
}

/* set intruder track angle and turn rate in "conventional" coordinate system */
trk = -actrk
if (trkrate_adjusted != 0.0) trkdot = -trkrate_adjusted
if (trkdot < 0.0) trk = trk + PI

/* Set time interval between prediction of straight tracks tangent to arc.
   The tracks should be 1.5 to 3.0 degrees apart (trkrate*dttrk) */
if (trkrate_adjusted != 0.0) {
     if (fabs(trkrate_adjusted) >= 3.0 * DEG_TO_RAD) dttrk = 0.5
     else if (fabs(trkrate_adjusted) >= 1.5 * DEG_TO_RAD) dttrk = 1.0
     else if (fabs(trkrate_adjusted) >= 0.75 * DEG_TO_RAD) dttrk = 2.0
     else dttrk = 4.0
     idtrk = dttrk/tstep + 0.5
}
else {
     idtrk = 999
}

/* Load evader aircraft position array */
maxstep = min(ctime,turntime)/tstep + 0.5
for (i=0 ; i<=maxstep ; i++) {
     xlocpos[i] = xloc + i*tstep*gsloc * cos_trkloc
     ylocpos[i] = yloc + i*tstep*gsloc * sin_trkloc
}

/* Check curved path with tangent tracks.  Set track angle. */
COStrk = cos(trk)
SINtrk = sin(trk)

for (iarc=0 ; iarc<=maxstep ; iarc++) {

          tpred = iarc*tstep
          xloc  = xlocpos[iarc]
          yloc  = ylocpos[iarc]

          /* Predict position along arc */
          xtrk = x0 + arcrad*(sin(trk+trkdot*tpred) - SINtrk)
          ytrk = y0 + arcrad*(cos(trk+trkdot*tpred) - COStrk)
```

```
            /* Check predicted position or tangent track depending on time */
            if ( fmod(iarc,idtrk) != 0) {
                /* Check predicted position */
                chkrange_full(tpred,xtrk,xloc,ytrk,yloc,e1c,e2c,e3c,e4c,
                            e1w,e2w,e3w,e4w,
                            ctime,wtime, t_enter_vert_caut, t_enter_vert_warn,
                            t_exit_vert_caut, t_exit_vert_warn, cbit,wbit,status)
            } else {
                /* Check tangent track */
                tantrk = actrk + tpred*trkrate_adjusted
                chktrack_full(tpred,t_enter_vert_caut,t_enter_vert_warn,
                        t_exit_vert_caut,t_exit_vert_warn,xloc,yloc,gsloc,trkloc,
                        xtrk,ytrk,gs,tantrk,e1c,e2c,e3c,e4c,e1w,e2w,e3w,e4w,
                        ctime,wtime,cbit,wbit,status)
            }   /* End of if-then-else for fmod(iarc,idtrk != 0) */
        }           /* End of for iarc = 0 to maxstep loop */
    } /* End of ilook = 1 to 2 for loop */
      return
    }           /* End of Subroutine Larcalert_full */
```

5.2 Subunit Chkvert_full Description

5.2.1 Subunit Chkvert_full Input Parameters

Variable	Type	Units	Description	Coordinate System
hloc	double	feet	evader altitude	intruder
hlocdot	double	ft/sec	evader altitude rate	intruder
h0	double	feet	intruder altitude	intruder
h0dot	double	ft/sec	intruder altitude rate	intruder
alvup	double	feet	vertical alert distance threshold above evader	
alvdown	double	feet	vertical alert distance threshold below evader	

Table 5.2.1 Subunit Chkvert_full Input Parameters

5.2.2 Subunit Chkvert_full Output Parameters

Variable	Type	Units	Description	Coordinate System
t_enter_vert	double	feet	entry time of intruder into evader's protected vertical zone	
t_exit_vert	double	feet	exit time of intruder from evader's protected vertical zone	
vflag	int	int	flag indicating that vertical intrusion has occurred	

Table 5.2.2 Subunit Chkvert_full Output Parameters

5.2.3 Subunit Chkvert_full Local Variables

Variable	Type	Units	Description	Coordinate System
h_ceil_thresh	double	feet	ceiling threshold above evader	
h_floor_thresh	double	feet	floor threshold below evader	
vert_sep_rate	int	int	vertical separation rate between intruder and evader.	

Table 5.2.3 Subunit Chkvert_full Local Variables

5.2.4 Subunit Chkvert_full Algorithm Pseudo Code

local constant definition:
ALT_RATE_DEADBAND = 0.1

```
Begin Chkvert_Full
{
*t_enter_vert = 999.0
*t_exit_vert = -999.0

/* Compute hockey puck ceiling and floor altitudes  */
h_ceil_thresh   = hloc + alvup
h_floor_thresh  = hloc - alvdown

/* Compute vertical separation rate.  */
vert_sep_rate = h0dot - hlocdot
```

```
if (h0 >= h_ceil_thresh) {
    /* adjacent ship is above the ceiling threshold  */
    if (vert_sep_rate >= -ALT_RATE_DEADBAND ){
        /* adjacent ship vertical separation constant or increasing */
        *vflag = FALSE
        return
    }
    else{
        /* adjacent ship vertical separation decreasing */
        *t_enter_vert = -(h0 - h_ceil_thresh)/vert_sep_rate
        *t_exit_vert  = -(h0 - h_floor_thresh)/vert_sep_rate
    }
} else if (h0 <= h_floor_thresh){
    /* adjacent ship is below the floor threshold  */
    if (vert_sep_rate <= ALT_RATE_DEADBAND ){
        /* adjacent ship vertical separation constant or increasing */
        *vflag = FALSE
        return
    }
    else{
        /* adjacent ship vertical separation decreasing */
        *t_enter_vert  = (h_floor_thresh - h0)/vert_sep_rate
        *t_exit_vert   = (h_ceil_thresh - h0)/vert_sep_rate
    }
} else{
    /* adjacent ship is between the ceiling and floor thresholds  */
    *t_enter_vert = 0.0
    if (vert_sep_rate >= ALT_RATE_DEADBAND){
        /* adjacent ship climbing relative to thresholds        */
        *t_exit_vert  = (h_ceil_thresh-h0)/vert_sep_rate
    }
    else if (vert_sep_rate <= -ALT_RATE_DEADBAND){
        /* adjacent ship descending relative to thresholds      */
        *t_exit_vert  = -(h0 - h_floor_thresh)/vert_sep_rate
    }
    else *t_exit_vert = 1000000.0 /* adjacent ship is relatively level */
}
*vflag = TRUE
return
}       /* End of Subroutine Chkvert_full */
```

5.3 Subunit Chkrange_full Description

Called from: Larcalert_full

Purpose: Check for instantaneous intrusion of the intruder in the evader's protected alert zone.

5.3.1 Subunit Chkrange_full Input Parameters

Variable	Type	Units	Description	Coordinate System
tpred	double	sec	time allotted for forward prediction of current states.	
xtrk	double	ft	x position along arc, start of tangent track	pursuer
ytrk	double	ft	y position along alrc, start of tangent track	pursuer
xloc	double	feet	x position of evader aircraft	pursuer
yloc	double	feet	y position of evader aircraft	pursuer
e1c	double		e1 coefficient for rotated caution ellipse	
e2c	double		e2 coefficient for rotated caution ellipse	
e3c	double		e3 coefficient for rotated caution ellipse	
e4c	double		e4 coefficient for rotated caution ellipse	
e1w	double		e1 coefficient for rotated warning ellipse	
e2w	double		e2 coefficient for rotated warning ellipse	
e3w	double		e3 coefficient for rotated warning ellipse	
e4w	double		e4 coefficient for rotated warning ellipse	
ctime	double	sec	states project-ahead time for determining caution alert	
wtime	double	sec	states project-ahead time for determining warning alert	
t_enter_vert _ caut	double	sec	time at which the pursuer will enter the evader's vertical protected threshold: caution level	
t_enter_vert _ warn	double	sec	time at which the pursuer will enter the evader's vertical protected threshold: warning level	
t_exit_vert_ caut	double	sec	time at which the pursuer will exit the evader's vertical protected threshold: caution level	
t_exit_vert_ warn	double	sec	time at which the pursuer will exit the evader's vertical protected threshold: warning level	
cbit	int		indice used to indicate access status to caution array	

Variable	Type	Units	Description	Coordinate System
wbit	int		indice used to indicate access status to warning array	

Table 5.3.1 Subunit Chkrange_Full Input Parameters

5.3.2 Subunit Chkrange_full Output Parameters

Variable	Type	Units	Description	Coordinate System
status[100]	int		Vector containing alerting routine status as well as other miscellaneous information	

Table 5.3.2 Subunit Chkrange_Full Output Parameters

5.3.3 Subunit Chkrange_full Local Variables

Variable	Type	Units	Description	Coordinate System
ellipse_ check_caut	double		elliptical range upper bound threshold factor for caution alert	
ellipse_ check_warn	double		elliptical range upper bound threshold factor for warning alert	
dx2	double		x difference between pursuer and evader squared	pursuer
dy2	double		y difference between pursuer and evader squared	pursuer
dxdy	double		cross term for x and y difference between pursuer and evader	pursuer

Table 5.3.3 Subunit Chkrange_full Local Variables

5.3.4 Subunit Chkrange_full Pseudocode

```
Begin Chkrange_Full
{
/* Check predicted position */
dx2 = (xtrk-xloc)*(xtrk-xloc)
dy2 = (ytrk-yloc)*(ytrk-yloc)
dxdy = (xtrk-xloc)*(ytrk-yloc)
ellipse_check_caut = e1c*dx2 + e2c*dxdy + e3c*dy2
ellipse_check_warn = e1w*dx2 + e2w*dxdy + e3w*dy2

/* Check for caution alert */
if ( (tpred <= ctime)
        && (ellipse_check_caut <= e4c)
        && (t_enter_vert_caut <= tpred)
        && (t_exit_vert_caut >= tpred) ) {
           status[cbit] = TRUE
}

/* Check for warning alert */
if ( (tpred <= wtime)
        && (ellipse_check_warn <= e4w)
        && (t_enter_vert_warn <= tpred)
        && (t_exit_vert_warn >= tpred) ) {
           status[wbit] = TRUE
}

return
}   /* End Chkrange_full */
```

5.4 Subunit Chktrack_full Description

Called from: Larcalert_full

Purpose: Check current fan leg for instantaneous intrusion of the intruder into the evader's protected alert zone.

5.4.1 Subunit Chktrack_full Input Parameters

Variable	Type	Units	Description	Coordinate System
tpred	double	sec	time allotted for forward prediction of current states.	
xtrk	double	ft	x position along arc, start of tangent track	pursuer

Variable	Type	Units	Description	Coordinate System
ytrk	double	ft	y position along alrc, start of tangent track	pursuer
gs	double	ft/sec	ground speed of pursuer aircraft	
xloc	double	feet	x position of evader aircraft	pursuer
yloc	double	feet	y position of evader aircraft	pursuer
gsloc	double	sec	ground speed of evader aircraft	
trkloc	double	rad	track angle of evader aircraft	pursuer
tantrk	double	rad	heading of tangent track	pursuer
e1c	double		e1 coefficient for rotated caution ellipse	
e2c	double		e2 coefficient for rotated caution ellipse	
e3c	double		e3 coefficient for rotated caution ellipse	
e4c	double		e4 coefficient for rotated caution ellipse	
e1w	double		e1 coefficient for rotated warning ellipse	
e2w	double		e2 coefficient for rotated warning ellipse	
e3w	double		e3 coefficient for rotated warning ellipse	
e4w	double		e4 coefficient for rotated warning ellipse	
ctime	double	sec	states project-ahead time for determining caution alert	
wtime	double	sec	states project-ahead time for determining warning alert	
t_enter_vert_caut	double	sec	time at which the pursuer will enter the evader's vertical protected threshold: caution level	
t_enter_vert_warn	double	sec	time at which the pursuer will enter the evader's vertical protected threshold: warning level	
t_exit_vert_caut	double	sec	time at which the pursuer will exit the evader's vertical protected threshold: caution level	
t_exit_vert_warn	double	sec	time at which the pursuer will exit the evader's vertical protected threshold: warning level	
cbit	int		indice used to indicate access status to caution array	

Variable	Type	Units	Description	Coordinate System
wbit	int		indice used to indicate access status to warning array	

Table 5.4.1 Subunit Chktrack_full Input Parameters

5.4.2 Subunit Chktrack_full Output Parameters

Variable	Type	Units	Description	Coordinate System
status[100]	int		Vector containing alerting routine status as well as other miscellaneous information	

Table 5.4.2 Subunit Chktrack_full Output Parameters

5.4.3 Subunit Chktrack_full Local Variables

Variable	Type	Units	Description	Coordinate System
dx	double	ft	aircraft x separation at time tpred	intruder
dy	double	ft	aircraft y separation at time tpred	intruder
dxdt	double	ft/sec	relative x axis groundspeed	intruder
dydt	double	ft/sec	relative y axis groundspeed	intruder
tau	double	sec	time to halfway between entry and exit	
t_enter_hor	double	sec	time that horizontal threshold is entered	
t_exit_hor	double	sec	time that horizontal threshold is exited	
t_end_check _caut	double	sec	time from current to end check (Caution)	
t_end_check _warn	double	sec	time from current to end check (Warning)	
time_band	double	sec	time width inside cylinder	
ellipse_ check	double		variable to compute ellipse bounds check	

Table 5.4.3 Subunit Chktrack_full Local Variables

5.4.4 Subunit Chktrack_Full Algorithm Pseudocode

local constant definition:
VERTEX_THRESHOLD = 0.05

```
Begin Chktrack_full
{
/* Compute relative position and relative ground speed */
dx = xtrk-xloc
dy = ytrk-yloc
dxdt = gs*cos(tantrk) - gsloc * cos(trkloc)
dydt = gs*sin(tantrk) - gsloc * sin(trkloc)

/* Check relative distances constant case) */
if ((fabs(dxdt) < 0.1) && (fabs(dydt) < 0.1)) {

   /* Check caution alert level */
   ellipse_check = e1c*dx*dx + e2c*dx*dy + e3c*dy*dy
   if ((ellipse_check <= e4c) && (t_enter_vert_caut < ctime) &&
     (t_exit_vert_caut > tpred)){
        status[cbit] = TRUE
   }

   /* Check warning alert level */
   ellipse_check = e1w*dx*dx + e2w*dx*dy + e3w*dy*dy
   if ((ellipse_check <= e4w) && (t_enter_vert_warn < wtime) &&
     (t_exit_vert_warn > tpred) && (tpred < wtime)){
        status[wbit] = TRUE
   }
   return
}


/* Evaluate case for caution alert                    */

/* Compute quadratic equation terms for time pursuer breach separation distance */
a = e1c*dxdt*dxdt +  e2c*dxdt*dydt + e3c*dydt*dydt
b = 2.0*e1c*dx*dxdt + e2c*(dx*dydt + dy*dxdt) + 2.0*e3c*dy*dydt


/* Compute time to halfway between entry and exit (tau)          */
/* Note: under elliptical formulation, tau represents halfway time between */
/* entry and exit times.  Not necessarily the point of closest approach    */
tau = -b/(2.0*a) + tpred
```

```
/* compute time at which we will no longer check for breach */
t_end_check_caut = ctime
if (t_exit_vert_caut <= t_end_check_caut) t_end_check_caut = t_exit_vert_caut

/* Evaluate quadratic to determine times of separation distance breach (if any) */
/* If necessary, determine collison status by comparison to vertical breach times */
c = e1c*dx*dx + e2c*dx*dy + e3c*dy*dy - e4c
d = b*b - 4.0*a*c
if (d <= -VERTEX_THRESHOLD) {
    /* intruder trajectory never breaches horizontal thresholds */
    /**MRCJ status[cbit] = FALSE   **/
} else if (d <= VERTEX_THRESHOLD) {
    /* intruder trajectory intersects horizontal thresholds at vertex */
    if ( (tau >= t_enter_vert_caut) && (tau <= t_end_check_caut)){
            status[cbit] = TRUE
        }
} else {
    /* intruder trajectory breaches horizontal thresholds */
    time_band = sqrt(d)/(2.0*a)
    t_enter_hor = tau - time_band
    t_exit_hor  = tau + time_band

    /* Check horizotal, vertical, and end check times for alert        */
    if (    (t_exit_hor > t_enter_vert_caut)
        && (t_enter_hor < t_end_check_caut)
        && (t_enter_vert_caut <= t_end_check_caut+0.01)
        && (t_exit_hor > tpred)
        && (t_exit_vert_caut > tpred)) {
            status[cbit] = TRUE
    }
}  /* End of if (d <= -VERTEX_THRESHOLD) clause */


/* Evaluate case for warning alert.                                    */

/* Compute quadratic equation terms for time pursuer breach separation distance */
a = e1w*dxdt*dxdt +  e2w*dxdt*dydt + e3w*dydt*dydt
b = 2.0*e1w*dx*dxdt + e2w*(dx*dydt + dy*dxdt) + 2.0*e3w*dy*dydt

/* Compute time to halfway between entry and exit (tau)                */
/* Note: under elliptical formulation, tau represents halfway time between */
/* entry and exit times.  Not necessarily the point of closest approach    */
tau = -b/(2.0*a) + tpred



/* Compute time at which we will no longer check for breach */
```

```
t_end_check_warn = wtime
if (t_exit_vert_warn <= t_end_check_warn) t_end_check_warn = t_exit_vert_warn

/* Evaluate quadratic to determine times of separation distance breach (if any) */
/* If necessary, determine collison status by comparison to vertical breach times */
c = e1w*dx*dx + e2w*dx*dy + e3w*dy*dy - e4w
d = b*b - 4.0*a*c
if (d <= -VERTEX_THRESHOLD) {
    /* intruder trajectory never breaches horizontal thresholds */
            /**MRCJ status[wbit] = FALSE  **/
} else if (d <= VERTEX_THRESHOLD) {
    /* intruder trajectory intersects horizontal thresholds at vertex */
    if ( (tau >= t_enter_vert_warn) && (tau <= t_end_check_warn)){
            status[wbit] = TRUE
        }
} else {
    /* intruder trajectory breaches horizontal thresholds */
    time_band = sqrt(d)/(2.0*a)
    t_enter_hor = tau - time_band
    t_exit_hor  = tau + time_band

    /* Check horizotal, vertical, and end check times for alert        */
    if (    (t_exit_hor > t_enter_vert_warn)
        && (t_enter_hor < t_end_check_warn)
        && (t_enter_vert_warn <= t_end_check_warn+0.01)
        && (t_exit_hor > tpred)
        && (t_exit_vert_warn > tpred)) {
            status[wbit] = TRUE
    }
} /* End of if (d <= -VERTEX_THRESHOLD) clause */


return
}               /* End Chktrack_full */
```

6 AILS Pre-Call and Post Call Requirements and Recommendations

This section describes processing that can or should be done prior to and after calling the AILS alerting algorithms, and describes how the algorithm should be called.

6.1 Overview and Flowchart For AILS Pre and Post-processing

The preprocessing that is performed prior to calling AILS can be classified by the level of importance. Some of the functions described in this section fall under the "required" category, some are declared as "recommended," while the rest fall into the " optional" classification. The descriptions of each function will indicate this classification. The level of importance is also reflected in the flow chart of Figure 6.2.1, which demonstrates a recommended sequence of processing for the functional blocks.

Depending upon the implementation and the format of the data that is available for AILS, some of the functional blocks and associated processing shown in Figure 6.2.1may increase or decrease in relevance and complexity.

6.2 Calling Rate for AILS

AILS Calling frequency = 1 HZ

Current analysis has been predicated on a design call frequency of 1 Hz. From an algorithm performance standpoint, it is not necessary to call AILS at a higher rate than 1 Hz. If implementation considerations require that this call frequency is lowered, additional analysis may be required to verify adequate system performance. The algorithm may actually perform worse at a higher execution rate since it will get more false alarms and would require additional processor throughput.

If the algorithm is to be called at a rate other than 1 HZ, no modifications are required to the call list of Larcalert_Full: There is no time step argument to the core AILS algorithm. However, prior to calling AILS, if a track rate filter (see section 6.5) is employed, the **deltat_call** to that filter should be appropriately adjusted.

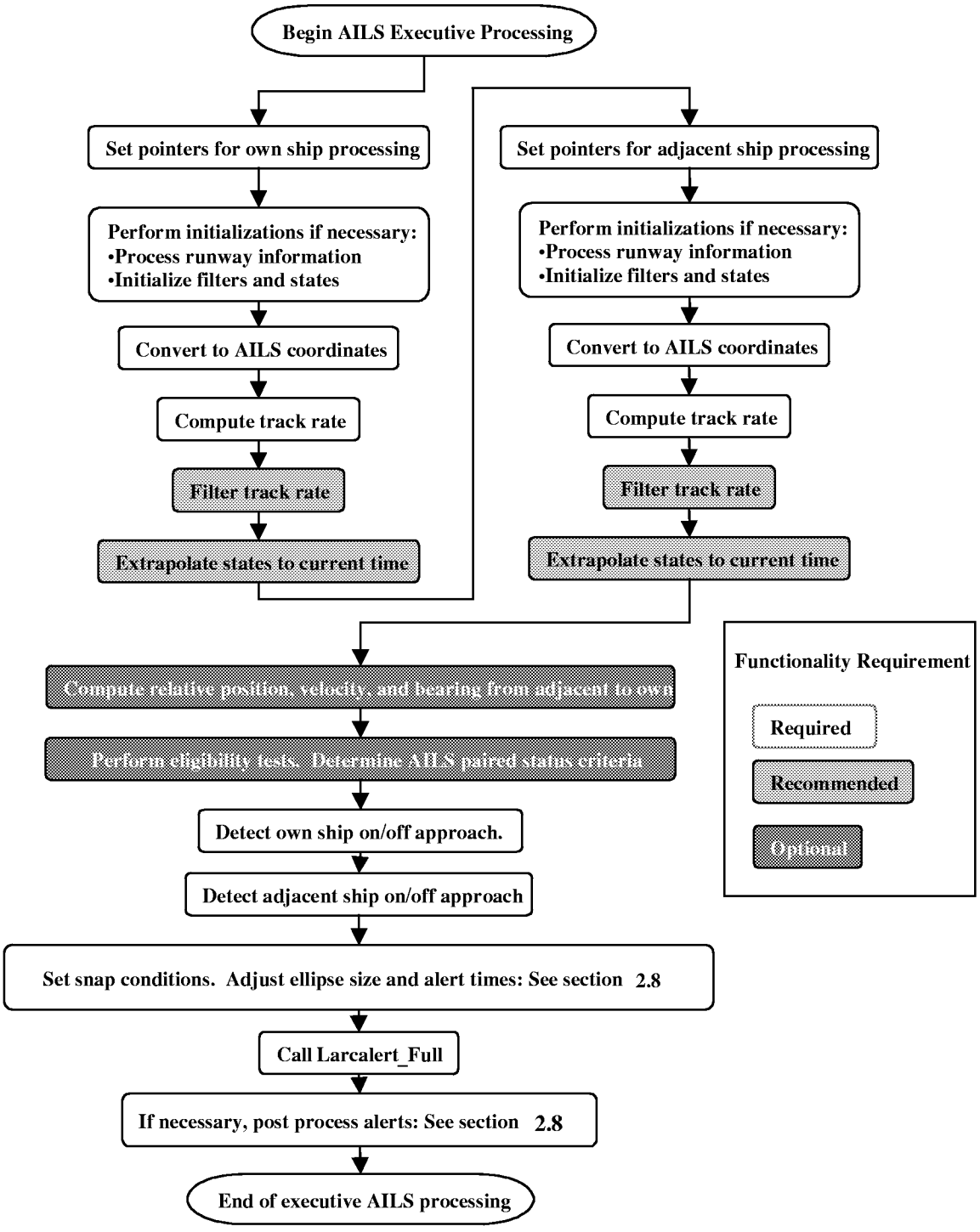

Figure 6.2.1 Relevant Pre and Post Processing For Larcalert_full

6.3 Conversion To AILS Coordinates

The format of the aircraft navigation variables will depend upon the specific components and implementation of the system that hosts AILS. These variables will likely need to be transformed from the available format into the local AILS runway coordinate system. This transformation will typically require the knowledge aircraft states in conjunction with the local approach parameters. Figure 6.3.1 below demonstrates such a conversion. The approach data will likely be constant, while the aircraft data will be periodic.

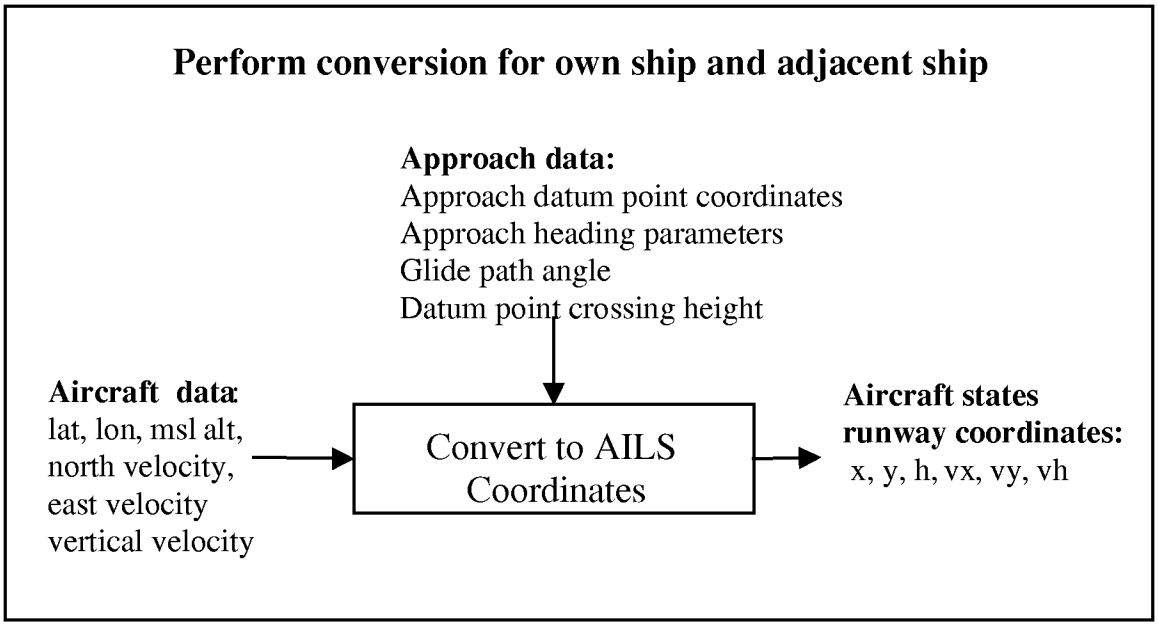

Figure 6.3.1 Conversion to AILS Coordinates

For detailed descriptions of the AILS local runway coordinate system, see section 3.2: Definition Of Internal AILS Coordinate System.

6.4 Track and Track Rate Derivation

During its trajectory predictions and extrapolations, AILS requires turn information in the form of track rate. Depending on the avionics of the implemented system, track rate may not be available. If not, track rate must be derived from the horizontal velocity vector components.

The following equations are a suggested derivation method for track track rate:

Equations For Track Rate Derivation
delta_time = time(k) – time(k-1)
track_angle(k) = atan2(ownship_velocity_east(k),ownship_velocity_north(k))
track_angle_rate(k) = (track_angle(k) – track_angle(k-1))/delta_time

Table 6.4.1 Equations For Track Rate Derivation

Note that the derived track angle is with respect to true north in a North-East-Down (NED) coordinate frame. This track and track rate may need to be further transformed into the AILS runway coordinate system.

It is also possible that the derived track rate can be noisy due to the differentiation of noisy velocity components. Section 6.5 discusses use of a track rate filter to alleviate this problem.

6.5 Track Rate Filter

Differentiated noisy velocity components will produce noisy derived track rates. Gusts, turbulence, and the pilot's flying characteristics will also contribute to noisy or exaggerated track rates.

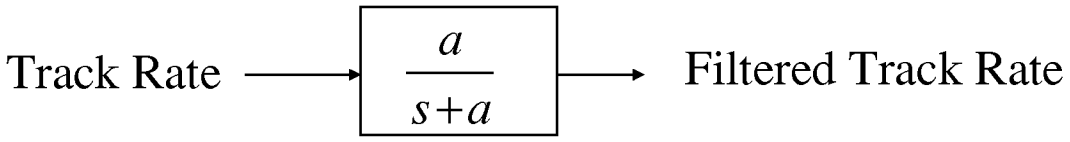

Figure 6.5.1 Track Rate Filter

Noisy track rates can affect the algorithm in an adverse manner because false or exaggerated turn rates can lead to misleading extrapolations of aircraft states. This can contribute to false alarm or unnecessary alert outcomes of AILS. It is therefore highly recommended that the derived track rates are filtered using a first order lag.

Rather than specifying the filter constant "a" directly, it is recommended that a frequency ratio factor be specified instead. This is to assure stability of the designed filter under all calling rates. The frequency ratio is defined as:

filter_frequency, a = frequency_ratio_factor / calling_period

This first order filter was digitally implemented for track-rate processing of the current version of AILS. The following parameters were used:

calling period = 1 sec

frequency_ratio_factor = .18

a = .18 radians/sec

6.6 Data Integrity Test

Current analysis of the AILS system will allow engineers to assess the performance of AILS under the implemented system configuration. Sensitivity analysis will show how system performance metrics will vary with the data characteristics. Data integrity limits can be deduced from such analysis and such limits should be applied in some form of data integrity test.

An example would be that of the horizontal position error from the differential GPS system. Sensitivity analysis can determine acceptable values of GPS system Horizontal Figure Of Merit (HFOM) that allow the system to meet performance metrics. Integrity limits can then be specified where failure to pass HFOM tests would preclude aircraft from being paired under AILS protection. Such tests should be applied for all relevant navigation data used by the AILS algorithm. The relevant data to be verified is listed:

- horizontal and vertical velocities
- horizontal and vertical positions

The analysis and tests should typically address the following attributes:

- uncorrelated errors (noise)
- first and second order errors of the states
- latency errors
- time tagging accuracy and time uncertainty errors
- parameter update rate

6.7 Extrapolate and Time Align Data

Aircraft position and velocity data that are available to the AILS algorithm prior to calling AILS will likely have originated from two sources: the own ship and the adjacent ship. Depending on the system and implementation, the data should have proper time tags associated with the time of validity of the data.

Prior to calling AILS, and prior to comparing the data in a common frame of reference, the data should be extrapolated and aligned to the current system time in the processor of the own ship.

This should be performed by using straight first order extrapolation of velocity to the position states:

x (extrapolated) = x (time_tagged) + dx/dt * time_delta_from_tagged_to_current

y (extrapolated) = y (time_tagged) + dy/dt * time_delta_from_tagged_to_current

h (extrapolated) = h (time_tagged) + dh/dt * time_delta_from_tagged_to_current

where the time_delta_from_tagged_to_current is the time delta between the time-of-validity for the data and the current time prior to calling AILS.

6.8 Compute Range, Range Rate, and Bearing to the Potential AILS Aircraft

Although not a requirement for output from AILS, it can be useful to compute values such as the relative range, range rate, and bearing to aircraft that are emitting ADS-B in the vicinity of the own aircraft. This information can be useful in determining if these aircraft are of potential threat (see section 6.9) to each other. In the case where the aircraft are NOT mutual threats, AILS would NOT be called which will prevent these values from being internally computed within AILS. If the user relied on these parameters for system functions such as displays, it is recommended that these values be computed outside of core AILS, regardless of whether or not AILS is called.

When the aircraft navigation states have been converted to local runway coordinates, the x, y, and h positions will be relative to each ship's runway datum point. Transformations must be performed to get the aircraft into a single coordinate system before the relative states can be computed. Such coordinate transformations were described in detail in section 3.2: Definition Of Internal AILS Coordinate System.

6.9 Determine AILS Aircraft Pairing

Recall that an AILS "pair" constitutes two aircraft that are in a simultaneous parallel approach situation and are under protection of the AILS algorithm: AILS is invoked with these aircraft as players in the own ship/adjacent ship scenario. Any particular aircraft on an approach at any time can be paired with more than one other aircraft that is of potential threat.

Aircraft should become eligible to be paired only if they are established on final approach. The AILS Path Length (APL) should be used as a factor to certify that an aircraft is close enough to the appropriate runway in order to be declared as being on final approach. Recall that once the inbound aircraft enter the APL, they may begin to lose the required 1000 ft vertical separation.

Once on final approach, it may still be impractical to pair all aircraft on the approach with all the other aircraft on the adjacent parallel approach. Only aircraft that can potentially threaten each other should be paired. It is therefore recommended that criteria should be established to determine which aircraft to designate as AILS pairs. The criteria can be based on parameters such as range and range-rate between the aircraft. Additionally, there should be smooth transitions between the predominant overall separation assurance system (probably TCAS) and

AILS alerting. The following subsection provides in C code form, the logic that was used to determine AILS pairing under configuration implemented in the simulation and flight tests in 1999.

6.9.1 Range Pairs Test Code

This supplemental section contains the code used to determine AILS pairing based on range and range rate. The determination of pairing is also a function of whether or not the aircraft being tested is currently paired. Therefore, the parameter **casper_pairs_flag** is an input/output parameter that reflects the pairing mode before this routine is called. The commanded pairing mode is reflected in the **casper_pairs_flag** upon return from the routine. Instructions for setting this flag can also be seen in Table 6.9.1.

variable	type	units	notes
range	double	feet	range to other aircraft
range_rate	double	feet/sec	range rate to other aircraft
casper_pairs_flag	int	boolean	Input/Output parameter. The current paired status with respect to the aircraft in question has to be properly reflected in this variable prior to call. Upon return, the commanded pairing status is reflected in the variable. **Input setting of casper_pairs_flag:** If currently paired, casper_pairs_flag = TRUE or 1 If currently not paired, casper_pairs_flag = FALSE or 0 Upon output, this flag is readjusted by the routine to reflect whether or to designate the aircraft as a pair. **Output result of casper_pairs_flag:** If casper_pairs_flag = 1 or TRUE , then paired If casper_pairs_flag = 0 or FALSE, then not paired

Table 6.9.1 Range Pairs Test Parameters

Following is the C code that was used to determine CASPER pairing:

```
#define DMOD_TURN_ON 9721.6      /* 1.6 nm */
#define DMOD_TURN_OFF 10633      /* 1.75  nm */
#define THRESHOLD_TIME 30.0

void  range_pairs_test (double range,double range_rate,int *casper_pairs_flag)
```

```
{
double adjusted_range_rate;
double tau_mod;

if (range_rate > 10.0) {

   /* perform diverging aircraft range test */
   if (*casper_pairs_flag == ON) {
     /* casper pairs mode is on, test for turn off */
     if (range > DMOD_TURN_OFF)
       *casper_pairs_flag = OFF;
     else
       *casper_pairs_flag = ON;
   } else {
     /* casper pairs mode is off, test for turn on */
     if (range > DMOD_TURN_ON)
        *casper_pairs_flag = OFF;
     else
        *casper_pairs_flag = ON;
   }

} else if (range_rate <= 10) {
   /* perform converging aircraft range test */

   /* compute adjusted range rate */
   if (range_rate > -10.0)
     adjusted_range_rate = -10.0;
   else
     adjusted_range_rate = range_rate;

   if (*casper_pairs_flag == OFF)
      /* casper mode is off, test for turn on */
      tau_mod = -(range-
(DMOD_TURN_ON*DMOD_TURN_ON)/range)/adjusted_range_rate;
   else
      /* casper pairs mode is on, test for turn off */
      tau_mod = -(range-
(DMOD_TURN_OFF*DMOD_TURN_OFF)/range)/adjusted_range_rate;

   if ((tau_mod - THRESHOLD_TIME) <= 0.0)
       *casper_pairs_flag = ON;
   else
       *casper_pairs_flag = OFF;

}
}
```

6.10 On-Approach/Off Approach Determination

AILS requires knowledge as to whether or not an aircraft is on or off of it's approach. The following criteria is used as a guideline:

Aircraft declared OFF APPROACH if either of the following conditions are true:

1. More than 2 dots of vertical deviation.
2. More than 2 dots of lateral deviation OR more than 400 ft of lateral deviation to either side of the approach path.

6.11 Ellipse and Time Parameter Adjustments

When one or both aircraft are off-approach, the alert parameters are adjusted since we know which aircraft is to blame for collision threats, as discussed in 2.8: Ellipse Size Adjustments If Aircraft is Off Approach.

6.12 Data Requirements Summary and Default Values

Table 5.1.1 in section 5.1.1 describes the input/output parameters to the Larcalert_full algorithm. Table 6.12.1 shows a summary of the input variables to AILS. Some of the variables to be provided to AILS are created by the preprocessing algorithms described in sections 6.1- 6.11. Other variables are algorithm design parameters that are simply set. The remainder of this section summarizes the requirements for all variables that are to be set.

6.12.1 AILS Parameter Input Summary Table

Variable Class	Characteristics	Variables	Description Reference
own aircraft states	changes with each call	osxpos, osypos, osgs, ostrk, ostrkdot, oshpos	Table 5.1.1
adjacent aircraft states	changes with each call	ajxpos, ajypos, ajgs, ajtrk, ajtrkdot, ajh	Table 5.1.1
own approach	constant	osglide,ostch	Table 3.5.1
adjacent approach	constant	ajglide,ajtch	Table 3.5.1
adjacent approach relative to own	constant	ajx_dp_offset, ajy_dp_offset, ajh_dp_offset	Table 5.1.3 Table 5.1.1
alerting parameters	constant, but parameters can be swapped if aircraft off approach	alvup, alvdown, aldst_e, protected_esc	Table 3.5.1 Table 5.1.1
algorithm parameters	constant	trkratedb, turntime, tstep	Table 5.1.1

Variable Class	Characteristics	Variables	Description Reference
snap flags	depends on if aircraft on approach	os_snap_flag, aj_snap_flag	Table 5.1.1

Table 6.12.1 AILS Parameter Input Summary

The following subsections describe the default settings and values for the AILS alerting and algorithm parameters. These are values used under the current AILS simulation and flight test configurations.

6.12.2 Default AILS Alerting Parameter Values

The following list is a summary of all the current default settings for AILS algorithm and alerting parameters:

aldst_e(LEVEL_1_DOWNRANGE) = 5000 (ft)

aldst_e(LEVEL_1_CROSSRANGE) = 1800 (ft)

alvup(LEVEL_1) =1800 (ft)

alvdown(LEVEL_1) = 1800 (ft)

altime(LEVEL_1) = 30 (sec)

aldst_e(LEVEL_2_DOWNRANGE) = 3500 (ft)

aldst_e(LEVEL_2_CROSSRANGE) = 1300 (ft)

alvup(LEVEL_2) =1300 (ft)

alvdown(LEVEL_2) = 1300 (ft)

altime(LEVEL_2) = 22 (sec)

aldst_e(LEVEL_3_DOWNRANGE) = 3400 (ft)

aldst_e(LEVEL_3_CROSSRANGE) = 1250 (ft)

alvup(LEVEL_3) =1250 (ft)

alvdown(LEVEL_3) = 1250(ft)

altime(LEVEL_3) = 21 (sec)

aldst_e(LEVEL_4_DOWNRANGE) = 2500 (ft)

aldst_e(LEVEL_4_CROSSRANGE) = 900 (ft)

alvup(LEVEL_4) =900 (ft)

alvdown(LEVEL_4) = 900 (ft)

altime(LEVEL_4) = 16 (sec)

6.12.3 Default AILS Algorithm Parameters

tstep = 0.5 (sec)

turntime = 99 (sec)

trkratedb = 0.00024 (rad/sec)

Note that selecting turntime = 99 sec, is effectively disabling the turn limit feature. See section 2.11 (page 12).

6.12.4 Default Protected Escape Zone Parameters

The following parameter values represent a defeated or disabled setting for the protected escape zone. The key switch to disable the zone is the lateral distance set to a very large negative number. This moves the protected zone far out in the direction opposite of the adjacently paired aircraft.

protected_esc[LATERAL] = -999999 (ft)

protected_esc[ABOVE] = 0 (ft)

protected_esc[BELOW] = 0 (ft)

protected_esc[AHEAD] = 0 (ft)

protected_esc[BEHIND] = 0 (ft)

6.13 Status Array Interpretation

The AILS main routine returns the status vector which indicates the **instantaneous** alerting status of AILS. The instantaneous status indicators are listed here:

status[LEVEL_1] = 0 or 1 : 1 indicates AILS level 1 alert TRUE , 0 indicates FALSE

status[LEVEL_2] = 0 or 1 : 1indicates AILS level 2 alert TRUE , 0 indicates FALSE

status[LEVEL_3] = 0 or 1 : 1 indicates AILS level 3 alert TRUE , 0 indicates FALSE

status[LEVEL_4] = 0 or 1 : 1 indicates AILS level 4 alert TRUE , 0 indicates FALSE

status[PROTECTED_ESC_LEV_3] = 0 or 1 : 1 indicates own ship in adjacent ship's protected escape zone, 0 indicates NO zone violation

status[PROTECTED_ESC_LEV_4] = 0 or 1 : 1 indicates adjacent ship in own ship's protected escape zone, 0 indicates NO zone violation

Recall the following alert status definitions:

Level 1 : Caution for own ship intruding at adjacent ship

Level 2 : Caution for adjacent ship intruding at own ship

Level 3 : Warning for own ship intruding at adjacent ship

Level 4 : Warning for adjacent ship intruding at own ship

Note that the status vector returned represents AILS operation based on instantaneous current information. There is no memory, persistence, or hysteresis effect on the alert levels. It is up to the user and calling routines to provide such conditions if desired. (For example, once a level 4 alert is issued, the top level operators will choose to impose a permanent level 4 situation. Likewise, some hysteresis effect may be desired for the alert levels to prevent on/off toggling status along the boundary conditions).

6.14 Static vs Dynamic Memory Allocation Requirements For AILS

Internal AILS has NO static variables.

Some of the variables that are involved in the preprocessing prior to AILS involve filters and states which will require some of those variables to be static.

7 AILS EQUATIONS

This section shows derivations of some of the equations that the AILS algorithms are based on.

7.1 Turn Radius

This section shows a derivation of turn radius that is used in a variety of locations.

$$\text{Side accel} = \frac{V_g^2}{\text{radius}} \qquad \textit{[Centripital acceleration]} \qquad (1)$$

$$\text{Lift} = \frac{m * g}{\cos\phi} \qquad \textit{[Vertical equilibrium]} \qquad (2)$$

$$\text{Side force} = \text{lift} * \sin\phi = m * g * \tan\phi \qquad (3)$$

$$g * \tan\phi = \frac{V_g^2}{\text{radius}} \qquad (4)$$

$$\text{Radius} = \frac{V_g^2}{g * \tan\phi} \qquad (5)$$

7.2 Inside A Rotated Ellipse

This section derives the equations used to detect if one aircraft is inside an ellipse shaped protected region of another aircraft. To accommodate non-parallel approach paths, the ellipse is rotated by the difference in approach headings (Figure 7.2.1 Rotated Ellipse Coordinates).

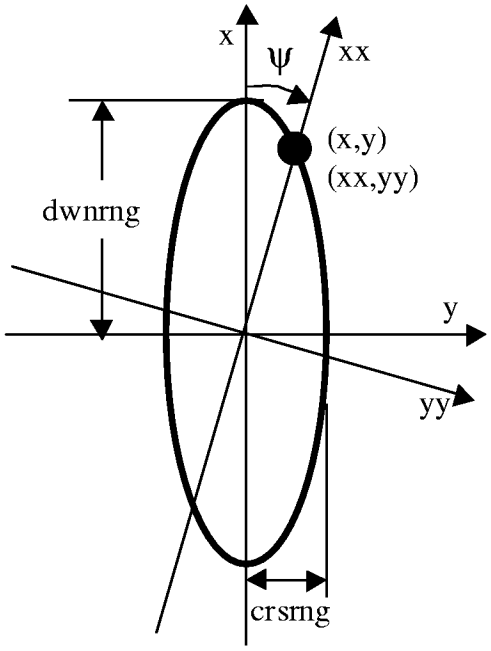

Figure 7.2.1 Rotated Ellipse Coordinates

First, the basic equations of an ellipse.

$$1 = \frac{x^2}{dwnrng^2} + \frac{y^2}{crsnrng^2} \quad (6)$$

$$dwnrng^2 crsrng^2 = crsrng^2 x^2 + dwnrng^2 y^2 \quad (7)$$

Then, the equations for a coordinate rotation.

$$x = xx \cos\psi - yy \sin\psi \quad (8)$$

$$y = xx \sin\psi + yy \cos\psi \quad (9)$$

Squaring these two equations:

$$x^2 = xx^2 \cos^2\psi - 2\, xx\, yy \cos\psi \sin\psi + yy^2 \sin^2\psi \quad (10)$$

$$y^2 = xx^2 \sin^2\psi + 2\, xx\, yy \cos\psi \sin\psi + yy^2 \cos^2\psi \quad (11)$$

Then, substituting these back into equation (7)

$$dwnrng^2 crsrng^2 = crsrng^2 (xx^2 \cos^2\psi - 2\, xx\, yy \cos\psi \sin\psi + yy^2 \sin^2\psi) + dwnrng^2 (xx^2 \sin^2\psi + 2\, xx\, yy \cos\psi \sin\psi + yy^2 \cos^2\psi) \quad (12)$$

and collecting terms.

$$dwnrng^2 crsrng^2 = (dwnrng^2 \sin^2\psi + crsrng^2 \cos^2\psi)\ xx^2 + (dwnrng^2 - crsrng^2) 2\cos\psi \sin\psi\ xxyy + (dwnrng^2 \cos^2\psi + crsrng^2 \sin^2\psi)\ yy^2 \quad (13)$$

Define 4 intermediate variables for convenience:

$$E1 = (dwnrng^2 \sin^2\psi + crsrng^2 \cos^2\psi) \quad (14)$$

$$E2 = (dwnrng^2 - crsrng^2) 2\cos\psi \sin\psi \quad (15)$$

$$E3 = (dwnrng^2 \cos^2\psi + crsrng^2 \sin^2\psi) \quad (16)$$

$$E4 = dwnrng^2 crsrng^2 \quad (17)$$

Then, the second aircraft is in the first aircraft's ellipse if:

$$E4 >= E1\ xx^2 + E2\ xx\ yy + E3\ yy^2 \quad (18)$$

7.3 Inside Ellipse For Future Track

To check if an aircraft will be in the ellipse of another aircraft at the current time or a future time, first the relative positions must be expressed.

$$dx(t) = x_{aj}(t) - x_{os}(t) \quad (19)$$

$$dy(t) = y_{aj}(t) - y_{os}(t) \quad (20)$$

To check if one aircraft is currently in the other aircraft's ellipse, equations (19) and (20) can be used for xx and yy in equation (18). (This is performed in subroutine CHKRANGE.)

To check if one aircraft will be in the other aircraft's ellipse in the future, the relative positions must be predicted in the future. (This is performed in subroutine CHKTRACK.)

$$dxdt = \frac{d}{dt} dx = V_{g_{aj}} * \cos trk - V_{g_{os}} * \cos trkloc \quad (21)$$

$$dydt = \frac{d}{dt} dx = V_{g_{aj}} * \sin trk - V_{g_{os}} * \sin trkloc \quad (22)$$

$$dx(t+\tau) = dx(t) + dxdt * \tau \quad (23)$$

$$dy(t+\tau) = dy(t) + dydt * \tau \quad (24)$$

Substituting equations (23) and (24) into equation (18) for xx and yy:

$$E4 = E1\ (dx + dxdt * \tau)^2 + E2\ (dx + dxdt * \tau)\ (dy + dydt * \tau) + E3\ (dy + dydt * \tau)^2 \quad (25)$$

Gathering terms, this can be expressed as a quadratic equation for τ.

$$a\tau^2 + b\tau^2 + c = 0 \quad (26)$$

$$a = E1\ dxdt^2 + E2\ dxdt\ dydt + E3\ dydt^2 \quad (27)$$

$$b = 2\ E1\ dx\ dxdt^2 + E2\ dx\ dydt + E2\ dy\ dxdt + 2\ E3\ dy\ dydt \quad (28)$$

$$c = E1\ dx^2 + E2\ dx\ dy + E3\ dy^2 - E4 \quad (29)$$

7.4 AILS Fan Equations

Figure 7.4.1 below shows how the equations for the aircraft position on the turn arc (xtrk, ytrk) can be developed.

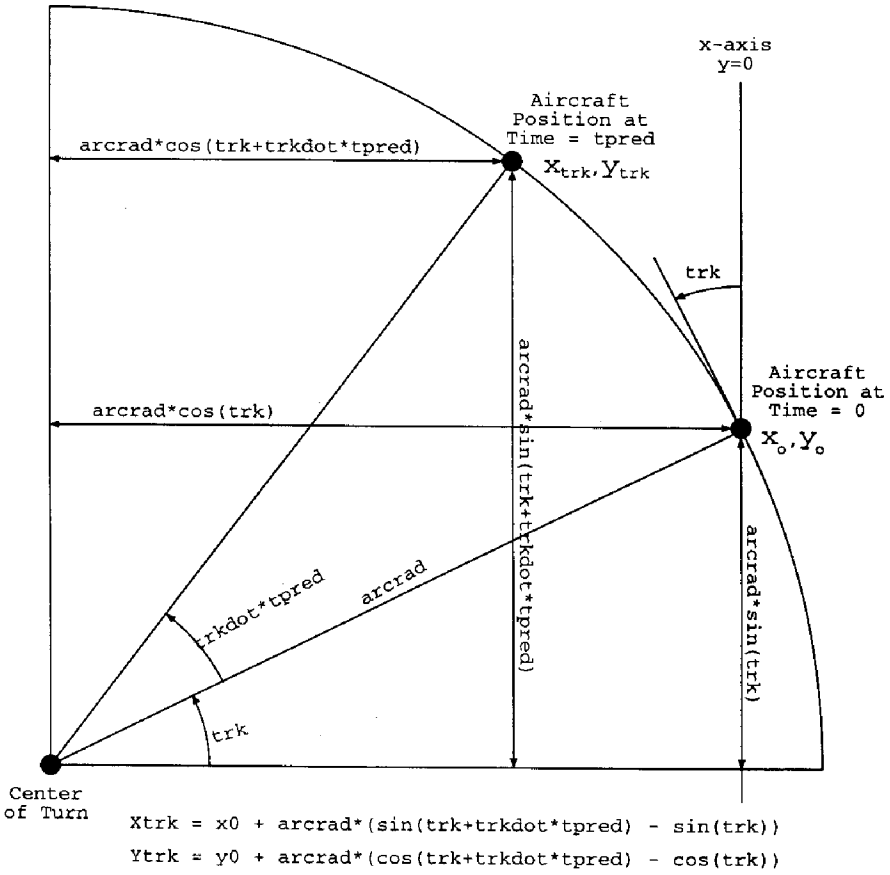

Figure 7.4.1 Calculation of Position on Turn Arc

8 Appendix A. Acronyms and Abbreviations

ADS-B	Automatic Dependent Surveillance-Broadcast
AILS	Airborne Information for Lateral Spacing
AJ	adjacent ship or other ship
APL	AILS Path Length
ATC	Air Traffic Control
Baro	barometric
CSPA	closely spaced parallel approaches
deg	degree
DGPS	Differential Global Positioning System
DME	distance measuring equipment
DP	datum point
ECEF	Earth-Centered, Earth-Fixed
EEM	Emergency Escape Maneuver
EFIS	Electronic Flight Instrument System
FMS	Flight Management System
FOM	figure of merit
ft	foot or feet
GNSSU	Global Navigation System Sensor Unit
GPS	Global Positioning System
IRS	Inertial Reference System
IRU	Inertial Reference Unit
LSB	least significant bit
kts	knots
m	meters
MAP	Missed Approach Procedure
MASPS	Minimum Aviation System Performance Standards
nm	nautical miles
OS	own ship
rad	radians
RTCA	Radio Technical Commission for Aeronautics
s, sec	second
SLS	Satellite Landing System
TBD	to be determined
TCAS	Traffic Alert and Collision Avoidance System
TCP	threshold crossing point
UTC	universal time coordinate
VHF	Very High Frequency

9 Appendix B. Glossary

AILS	The NASA program for developing alerting algorithms for closely spaced parallel approaches. Also refers to the alerting logic used once the aircraft are established on a parallel approach.
AILS Path Length	The distance from the runway threshold to the point where we start separating the aircraft with AILS
ARINC	Communications standard
CASPER	The Honeywell program for developing alerting algorithm for closely spaced parallel approaches. Also refers to the algorithms wrapped around AILS that assign CASPER targets, do integrity checking, and manage the interaction with TCAS.
CASPER target	Aircraft for which we provide blunder protection using the CASPER/AILS system. All other aircraft are TCAS targets
glidepath	The three-dimensional path in space that describes the approach path
glideslope angle	The angle between the glidepath and a horizontal plane tangent to the Earth's surface at the datum point
TCAS target	Aircraft for which collision avoidance protection is provided by TCAS. This is true for all aircraft except those on a parallel runway for which we use the AILS alerting algorithms for protection.

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13. ABSTRACT (*Maximum 200 words*)

This document provides a complete description of the Airborne Information for Lateral Spacing (AILS) alerting algorithms. The purpose of AILS is to provide separation assurance between aircraft during simultaneous approaches to closely spaced parallel runways. AILS will allow independent approaches to be flown in such situations where dependent approaches were previously required (typically under Instrument Meteorological Conditions (IMC)). This is achieved by providing multiple levels of alerting for pairs of aircraft that are in parallel approach situations.

This document's scope is comprehensive and covers everything from general overviews, definitions, and concepts down to algorithmic elements and equations. The entire algorithm is presented in complete and detailed pseudo-code format. This can be used by software programmers to program AILS into a software language. Additional supporting information is provided in the form of coordinate frame definitions, data requirements, calling requirements as well as all necessary pre-processing and post-processing requirements. This is important and required information for the implementation of AILS into an analysis, a simulation, or a real-time system

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